WHOI-99-02

Woods Hole Oceanographic Institution

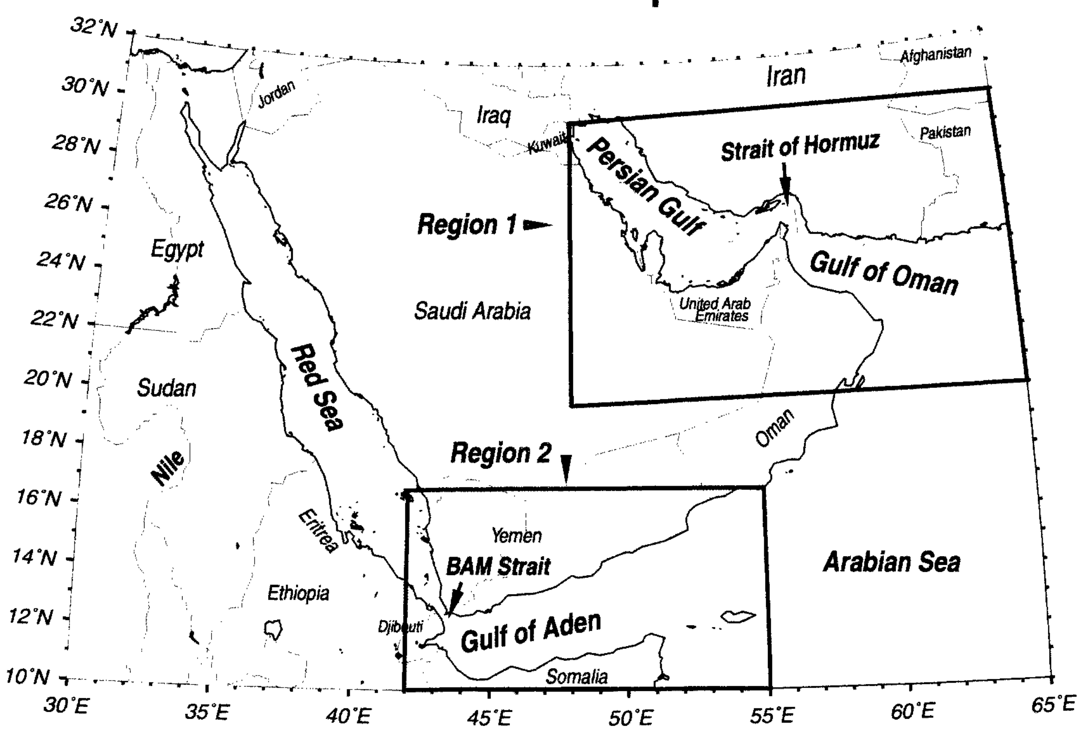
Hydrographic Data from the U.S. Naval Oceanographic Office: Persian Gulf, Southern Red Sea, and Arabian Sea 1923-1996

By

Carol A. Alessi, Heather D. Hunt and Amy S. Bower

April 1999

Technical Report



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Approved for Distribution:

Terrence M. Joyce

Terrence M. Joyce, Chair

Department of Physical Oceanography

Table of Contents

List of Tables ii

List of Figures ii

List of Figures for Regions 1 and 2 iii

Abstract iv

1. **Introduction** 1

2. **The Data Source** 1

3. **Overview of the Quality Control Method** 2
   - 3.1 **The HydroBase Utility Package** 2
   - 3.2 **Data Organization** 7

4. **Quality Control Procedure** 8
   - 4.1 **Range Checking the Data** 8
   - 4.2 **Statistical Checking** 9
     - 4.2.1 **Region 1: Description of Data Groupings** 12
     - 4.2.2 **Region 2: Description of Data Groupings** 13
   - 4.3 **Visual Scan** 17
   - 4.4 **The Final Quality Controlled Data Set** 17

5. **Description of Data Presentation** 19

6. **Acknowledgments** 22

7. **References** 22

8. **Data Presentation for Region 1** 23

9. **Data Presentation for Region 2** 45

List of Tables

Table 1. Hydrographic data from NAVOCEANO for the Persian Gulf, southern Red Sea, and Arabian Sea 4

Table 2. Region 1 Data Groupings 10

Table 3. Region 2 Data Groupings 11

Table 4. Number of profiles and scans before and after QC 17

Table 5. Seasonal Definitions for Data Presentation 19

List of Figures

Figure 1. Chart of the study area 3

Figure 2a. Elevation map of Region 1 5

Figure 2b. Elevation map of Region 2 5

Figure 3. Sub-square coding for 10° and 1° Marsden Square Numbers 7

Figure 4. Geographical subdivisions and bathymetry: Region 1 12

Figure 5. Geographical subdivisions and bathymetry: Region 2 13

Figure 6. Results of quality control for a standard pass 15

Figure 7. Results of quality control where the standard deviation was increased . 16

Figure 8. Vertical distribution of original and QC data 18

Figure 9. Bar graph of yearly distribution of data 19

Figure 10. Station Locations for Region 1 by Month 20

Figure 11. Station Locations for Region 2 by Month 21

Data Presentation for Region 1 23
Figure 12. 1204_box1 25
Figure 13. 1204_box2 26
Figure 14. 1205_box3 27
Figure 15. 1205_box4 28
Figure 16. 1205_box5 29
Figure 17. 1205_box6 30
Figure 18. 1205_box7 31
Figure 19. 1205_box8 32
Figure 20. 1205_box9 33
Figure 21. 1205_box10 34
Figure 22. 1205_box11a 35
Figure 23. 1206_box11b 36
Figure 24. 1206_box11c 37
Figure 25. 1206_box11d 38
Figure 26. 1206_box11e 39
Figure 27. 1206_box11f 40
Figure 28. 1206_box11g 41
Figure 29. 1206_box11h 42
Figure 30. 1206_box11i 43
Figure 31. 1206_box11j 44

Data Presentation for Region 2 45
Figure 32. 1104_box1 47
Figure 33. 1104_box2 48
Figure 34. 1104_box3 49
Figure 35. 1104_box4 50
Figure 36. 1104_box5 51
Figure 37. 1104_box6 52
Figure 38. 1104_box7 53
Figure 39. 1104_box8 54
Figure 40. 1104_box9 55
Figure 41. 1104_box10 56
Figure 42. 1105_52 57
Figure 43. 1105_box11a 58
Figure 44. 1105_box11b 59
Figure 45. 1105_box11c 60
Figure 46. 1105_box11d 61
Figure 47. 1105_box11e 62

On The Cover: Chart of the study area. The boxed areas represent **Region 1** *and* **Region 2**, *the two regions for which we obtained NAVOCEANO data.*

Abstract

Temperature-salinity-depth profile data were obtained for the Persian Gulf, southern Red Sea and parts of the Arabian Sea from the Master Oceanographic Observations Data Set (MOODS), located at the U.S. Naval Oceanographic Office (NAVOCEANO), Stennis Space Center, Mississippi. These data were used as part of a physical oceanographic study of the Red Sea and Persian Gulf outflows. This report documents the organization of the data set and the method of quality control used to eliminate unrealistic data. Also, it provides a summary in graphic form of the hydrographic observations.

1. Introduction

The Red Sea and Persian Gulf are the source regions for two of the most saline water masses found in the World Ocean (Rochford, 1964). Red Sea Water and Persian Gulf Water are the result of extremely high evaporation rates (2 m yr^{-1}, Privett, 1959), insignificant rainfall and river inflow, and restricted exchange with the open ocean. Both seas are connected to the Indian Ocean through a shallow narrow strait: the Bab-el-Mandeb (BAM) Strait, with a sill depth of 160 m, connects the Red Sea to the Gulf of Aden; and the Strait of Hormuz, which has a sill depth of 80 m, leads from the Persian Gulf into the Gulf of Oman, Figure 1. These saline water masses flow out of the marginal seas as dense bottom currents, cascading down the continental slope and entraining less dense Indian Ocean water until they reach neutral buoyancy. They can be traced throughout large portions of the Indian Ocean due to their high salinity (Wyrtki, 1971).

As part of a study of the Red Sea and Persian Gulf outflows, public-domain temperature-salinity-depth (TSD) profile data were obtained from the Master Oceanographic Observation Data Set (MOODS) archive facility at the U.S. Naval Oceanographic Office (NAVOCEANO), Stennis Space Center, Mississippi. Figure 1 shows the two areas of interest: **Region 1** refers to the Persian Gulf, Strait of Hormuz, Gulf of Oman, and northern Arabian Sea; **Region 2** refers to the southern Red Sea, BAM Strait, Gulf of Aden, and western Arabian Sea. The purpose of this report is to document the quality control (QC) procedures used to edit the hydrographic data, and to present in graphic form a summary of the final data set.

2. The Data Source

The data obtained from NAVOCEANO consisted of 2885 temperature-salinity profiles for Region 1 and 4185 profiles for Region 2 (Table 1). For comparison, the overall number of profiles after the QC process is shown in bold lettering. The QC procedure is described in Section 4. The data set presented here spans 74 years of observations, from 1923 to 1996. There are several types of data (originating from a variety of sources) in this data set, necessitating a quality control analysis. However, the majority of the hydrographic data come from hydrocast (bottle) and CTD measurements. The geographical distribution of the observations (after quality control) is shown in Figures 2a and 2b for Regions 1 and 2, respectively.

3. Overview of the Quality Control Method

The quality control method used was originally developed for the purpose of producing a new North Atlantic climatology by Lozier *et al.* (1995). In brief the TSD data were first grouped into subregions (and in some cases seasons) that exhibited a similar potential temperature-salinity (T-S) relationship. The data were then averaged in density bins to obtain a mean T-S relationship for each subregion, and individual observations more than 2.3 standard deviations away from the mean T-S curve were eliminated. As pointed out by Curry (1996), this method does not guarantee that all erroneous observations are eliminated, nor that all good data are retained. It is simply an objective, statistical approach to removing observations that have a high likelihood of being incorrect.

This differs from previous quality control methods (*e.g.*, Levitus and Boyer 1994), where averaging on pressure surfaces, especially in the upper 1000m, distorts the T-S relation within depth bins. The method of isopycnal averaging avoids creating unrealistic water properties. This procedure is explained in detail by Curry (1996).

3.1 The HydroBase Utility Package

The utilities used were part of a package called HydroBase (Curry, 1996). HydroBase is an interface to help manage data, optimized for fast data writing and retrieval of the data. The utilities were modified to reflect the appropriate information for our study area. The main modifications to the HydroBase utilities were as follows:

- First, we used minimum and maximum temperature and salinity values appropriate for the study area for the initial range-checking step of the quality control procedure. The values were selected using the Oceanographic Atlas of the International Indian Ocean Expedition (Wyrtki, 1971).

- Second, we defined the density levels for averaging based on the shape of the theta-S curves in our study area.

- Third, in limited areas, we accepted data outside the normal limits of statistical tolerance because these areas are known to be highly variable in theta-S characteristics (outflow areas).

These modifications, concerning the maximum absolute temperature and salinities, and appropriate density bin divisions, are discussed in Section 4.

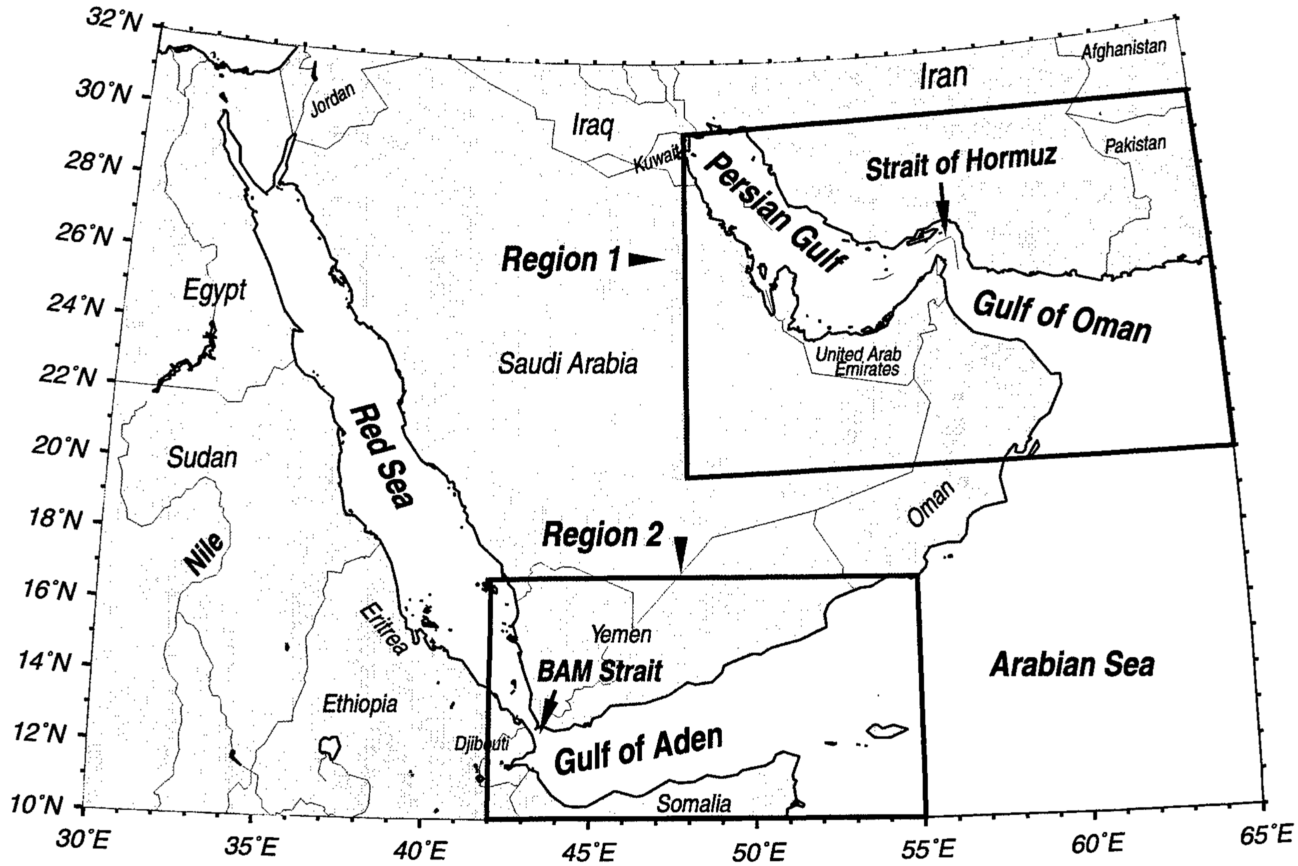


Figure 1. Chart of the study area. The boxed areas represent, starting with the most northern, **Region 1** and **Region 2,** the two regions for which we obtained NAVOCEANO data.

Table 1: Historical data from NAVOCEANO: Persian Gulf, Southern Red Sea, and Arabian Sea

Region 1: Area Latitudes: 20° N – 30° N, Area Longitudes: 48° E – 65° E

Region 2: Area Latitudes: 10° N – 17° N, Area Longitudes: 42° E – 55° E

Number of Profiles by Instrument

Number of Profiles				
Region-2		Region-1		Description of Instrument
Original	**QC**	*Original*	**QC**	
41	**40**	188	**181**	Message Data
3	**3**	0	**0**	Air-Deployed CTD (AXCTD)
802	**762**	1054	**952**	Hydrocast
2999	**2944**	371	**335**	Electronic D/T/S Inst
4	**3**	30	**21**	STD
259	**257**	18	**10**	Low Resolution STD from NODC
65	**65**	1161	**1109**	CTD
2	**2**	50	**50**	Time Series CTD
2	**2**	6	**6**	SVSTD
8	**8**	7	**7**	XCTD (Sippican)
4185		2885		Original Total: 7070
	4086		**2671**	**QC Total: 6757**

Number of Profiles by Source

Number of Profiles		
Region-2	Region-1	Description of Source
39	0	FNMOC Message Data
679	528	NODC SDII
16	27	STD data from Scripps
46	442	NODC 022 (high res CTD/STD)
16	122	FNMOC update data
0	4	U.S. Navy XBT/XSV/CTD
76	423	NODC CDROM World Ocean Atlas 1994
3260	373	NODC Ocean Clim Lab, Sydney, L
51	778	NAVOCEANO CTD, STD, SVSTD
2	188	NAVOCEANO GOODS TESAC
4185	**2885**	**Totals**

Table 1. The data obtained from NAVOCEANO consisted of 2885 temperature-salinity profiles for Region 1 and 4185 profiles for Region 2 . The overall number of profiles after the QC process is shown in bold lettering.

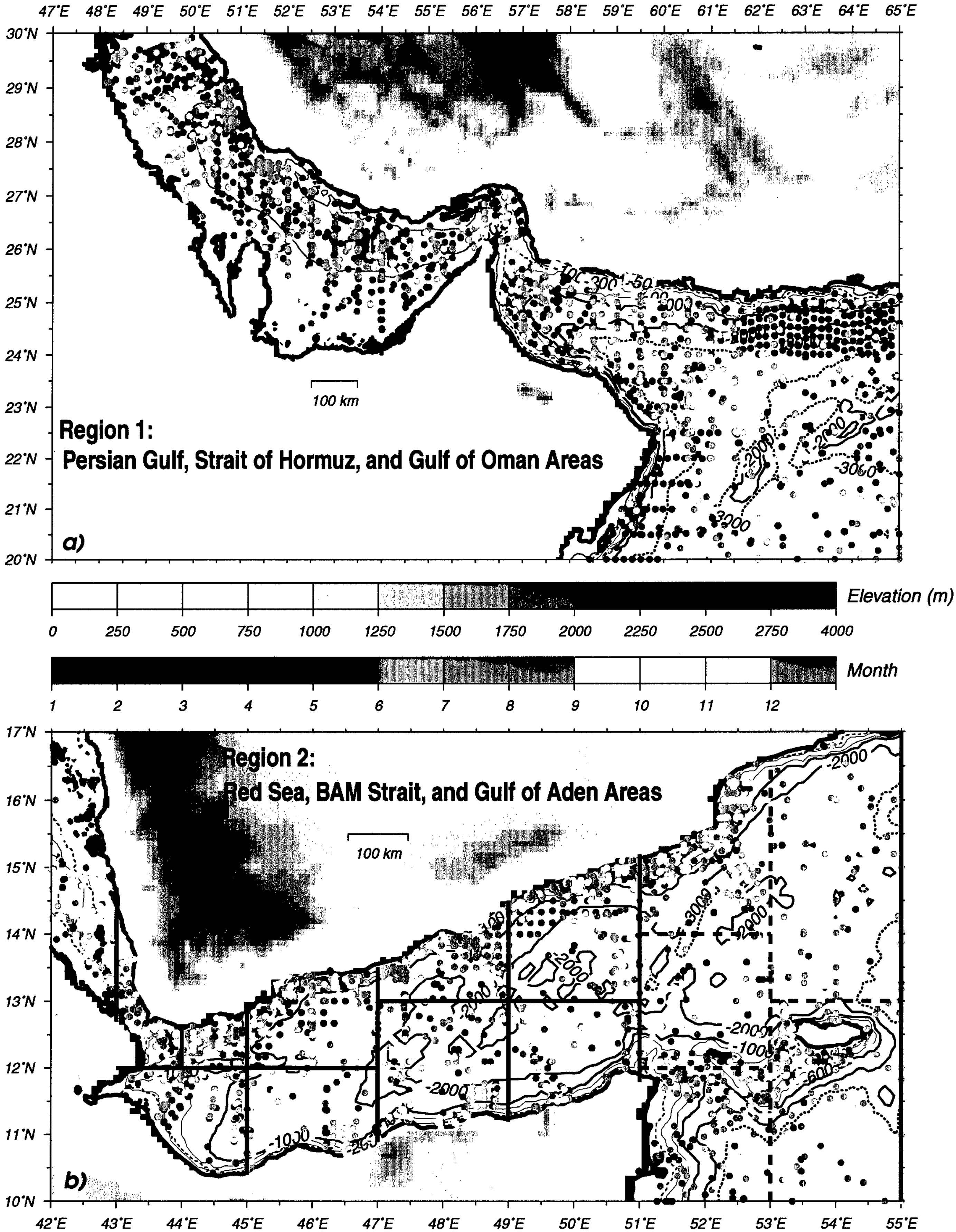


Figure 2: Elevation maps for a) Region 1, and b) Region 2. The colored dots indicate the geographical distribution of observations (after QC) by month.

3.2 Data Organization

Before the quality control method was applied, the data were arranged geographically by 10° and 1° Marsden Square numbers. Within each 10° square there are one hundred 1° sub-squares, coded 00 through 99. The sub-squares are oriented so that the lowest number (00) is nearest the equator and the Greenwich meridian. Figure 3 shows the sub-square coding for the 10° and 1° squares, which is what we used as part of our file naming convention (*i.e.,* **10deg_1deg.w01**). For example, to obtain the data in the BAM Strait, the filename designation would be 1104_23.w01. To obtain the entire 10° square, the filename would be 1104.w10.

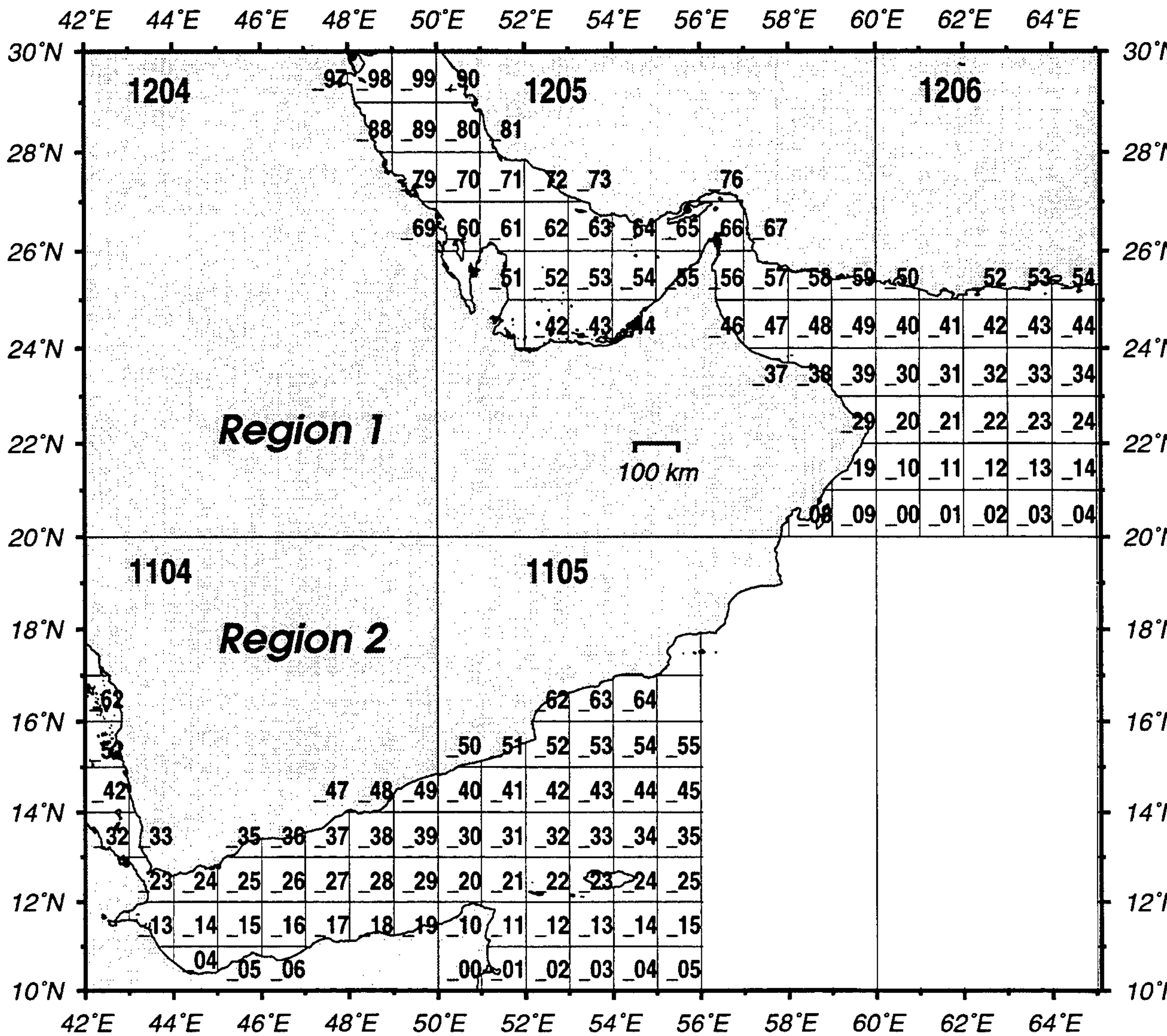


Figure 3. Sub-square coding for 10° and 1° Marsden Square Numbers.

4. Quality Control Procedure

There were three steps in the quality control procedure to identify outliers.

- **Range checking** the data removed data points outside the range of realistic values for the study area. Mininum and maximum temperature and salinity ranges are selected for each region (Section 4.1). During this initial processing step, because both temperature and salinity are needed to compute potential density (relative to the sea surface), if an observation level was missing either a temperature or salinity value, the observation was eliminated. This preliminary step eliminated **less than 0.2%** of the data for Region 1 and Region 2 (1719 scans were eliminated out of a possible 909,207 scans);

- **Statistical checking** removed observations lying outside a defined range of the local mean theta-S relationship. The local mean theta-S curve is obtained by averaging the theta-S observations in density bins, which are defined for each local area (Section 4.2); and

- **Visual scan** of the profile plots allowing for a broader check, especially in those regions which had been divided very finely geographically in the statistical check. (Section 4.3).

4.1 Range Checking the Data

To identify questionable data points, temperature and salinity ranges were defined as a function of the maximum and minimum values within geographic regions using the Oceanographic Atlas of the International Indian Ocean Expedition (Wyrtki, 1971). These ranges were used to identify and remove points which fell outside the acceptable limits of salinity or temperature. Several sets of limits were used, depending on the region (Tables 2 and 3).

4.2 Statistical Checking

The broad geographic regions of **Region 1** (20° – 30° N, 48° – 65° E), and **Region 2** (10° – 18° N, 42° – 55° E) were divided into subregions with similar theta-S relationships. These subregions were the Red Sea, BAM Strait, Gulf of Aden, Persian Gulf, Strait of Hormuz, and the Gulf of Oman.

The data were further sub-divided to reduce computation time while maintaining the maximum number of profiles per division. In the shallower and enclosed marginal seas and straits, the seasonal change in the theta-S relationship was extreme. For these areas, profiles were split into summer and winter groups and processed separately. The boundaries of the various subregions are shown in Figures 4 and 5.

The next step was to average the data in each subregion in density intervals to obtain a mean theta-S curve for the subregion, and eliminate observations more than 2.3 standard deviations away from that mean curve. A set of density bins appropriate to each subregion was developed by examining the relationship of the theta-S profiles to the isopycnals on the theta-S diagram. In general, inflection points on the theta-S curve were treated with finer density bin resolution. Tables 2 and 3 list the density resolution of each geographic area.

For each area, the slope, intercept, and standard deviation were calculated for the data in each density bin to characterize the theta-S relationship. Each temperature and salinity observation was compared with the statistics in the appropriate density bin. Once the isopycnal bins were chosen, any observation which fell outside 2.3 standard deviations from the line were eliminated. For profiles having greater than 20% of observations falling outside the cut-off, the entire profile was eliminated.

There were two regions (west of 49° E in the Gulf of Aden and the Gulf of Oman, and Arabian Sea, Table 3) where it was necessary to increase the "multiplier" (factor multiplied times the standard deviation) for some density bins (Tables 2 and 3). The multiplier was increased where the overflow water from the marginal seas increased the theta-S variability within the overflow water layer. Figure 6 shows the QC results during a standard pass through the data. Figure 7 shows the results of a case where the standard deviation multiplier was increased for sigma-0 26.4 through 27.6, from 2.3 to 3.0.

Tables 2 and 3 list the geographic subregions, along with the 10° _1° Marsden Square filenames used in that region; a definition for each "boxed" region; the ranges of acceptable salinity and temperature; seasonal definitions, if any; and density resolutions appropriate to each area.

Table 2: Region 1 Data Groupings

Region	Geo Boxes	Max/Min Salinity	Max/Min Theta	Seasonal Divisions	Density Bins	Comments
Persian Gulf (Msq 1204/1205) 1204_88,_97,_98,_99, and 1205_90	Seasonal Def #1	44.0/35.0	35.0/10.0	Summer: May–Nov	pgulf_hz.bins S0=[22.0:0.4:31.0]	Figure 4
Persian Gulf (1204/1205) 1204_88,_97,_98,_99, and 1205_90	Box 1			Winter: Dec–Apr	pgulf_hz.bins	
Persian Gulf (1204/1205) 1204_89,_79,_69, and 1205_50,_60,_70,_80	Seasonal Def #2 Box 2	44.0/35.0	35.0/10.0	Summer: Apr–Nov	pgulf_hz.bins	
1205_41,_51,_61,_71 1205_42,_52,_62,_72 1205_43,_53,_63 1205_44,_54,_64	Box 3 Box 4 Box 5 Box 6					Longitude Strips 51E–52E 52E–53E 53E–54E 54E–55E
Persian Gulf (1204/1205) 1204_89,_79,_69, and 1205_50,_60,_70,_80	Box 2			Winter: Dec–Mar	pgulf_hz.bins	
1205_41,_51,_61,_71 1205_42,_52,_62,_72 1205_43,_53,_63 1205_44,_54,_64	Box 3 Box 4 Box 5 Box 6					Longitude Strips 51E–52E 52E–53E 53E–54E 54E–55E
Strait of Hormuz (1205) _55,_65,_46,_45, _66,_76,_57,_67	Box 7	42.0/34.0	35.0/10.0	Summer: Jun–Nov	pgulf_hz.bins	Stations LE 200 m
Strait of Hormuz (1205) _55,_65,_46,_45, _66,_76,_57,_67				Winter: Dec–May	pgulf_hz.bins	Stations LE 200 m
Gulf of Oman (1205) _46,_56,_57, and all stations in _37,_47	Box 8	39.0/34.0	35.0/1.0	None	oman.bins S0=[22.0:1.00:25.0] [25.0:0.50:25.5] [25.5:0.20:28.0] S2=[36.0:0.25:38.0] S4=[45.5:1.00:46.5]	Stations GT 200 m Boxes 8,9,10: Increase multiplier from Sigma-0=26.0 through Sigma-0=27.0 from 2.3 to 3.0
1205_38,_48,_58	Box 9					
1205_29,_39,_49,_59	Box 10					
Arabian Sea (1205/1206)	Box 11	39.0/34.0	35.0/1.0	None	arabian.bins S0=[22.0:1.00:25.0] [25.0:0.50:25.5] [25.5:0.25:27.0] [27.0:0.20:28.0] S2=[36.0:0.25:38.0] S4=[45.5:1.00:46.5]	Boxes 11a-j: Increase multiplier from Sigma-0=26.0 through Sigma-0=27.0 from 2.3 to 3
Msq 1205 _08,_09,_19	11a					
Msq 1206 _40,_41,_50,_51	11b					
_42,_43,_52,_53	11c					
_44,_45,_54,_55	11d					
_20,_21,_30,_31	11e					
_22,_23,_32,_33	11f					
_24,_25,_34,_35	11g					
_00,_01,_10,_11	11h					
_02,_03,_12,_13	11i					
_04,_05,_14,_15	11j					

Table 2 lists for Region 1 the geographic subregions along with the 10° and 1° Marsden square filename identification; a definition for each "boxed" region; the ranges of acceptable limits for salinity and temperature; seasonal definitions; and density resolutions appropriate to each area.

Table 3: Region 2 Data Groupings

Region April 14, 1999	Geo Boxes	Max/Min Salinity	Max/Min Theta	Seasonal Divisions	Density Bins	Comments
Red Sea Msq (1104) 1104_32, 1104_42, 1104_52, 1104_62	12N–17N 42E–43E Box 1	41.0/34.0	35.0/1.0	Summer: July–Nov	redseaS.bins S0=[22.0:1.0:23.0] [23.0:0.5:26.0] [26.0:0.2:27.6] [27.6:0.1:28.6] [28.6:0.2:29.0]	Figure 5 two passes each for S/W
Red Sea 1104_32, 1104_42, 1104_52, 1104_62				Winter: Dec–June	redseaW.bins S0=[22.0:0.2:29.0]	
BAM Strait 1104_23,1104_33	N of 12.4N 43E–43.55E Box 2	41.0/34.0	35.0/1.0	Summer JuneS–Nov	redseaS.bins	June Summer Stations 12.50N 43.50E 1958 06 12 12.83N 43.23E 1950 06 07
BAM Strait 1104_23,1104_33				Winter Dec–JuneW	redseaW.bins	June Winter Stations 12.80N 43.25E 1958 06 12 12.70N 43.27E 1958 06 12
Gulf of Aden 1104_23,1104_24	Box 3	41.0/34.0	35.0/1.0	None	goa_as.bins	Use remainder of stations in square _23 plus all of 1104_24
West of 49° E (1104) _03,_04,_13,_14 _25,_26,_35,_36 _37,_38,_47,_48 _17,_18,_27,_28 _05,_06,_15,_16	Box 4 Box 5 Box 7 Box 8 Box 6				S0=[21.0:1.0:25.0] [25.0:0.5:26.0] [26.0:0.2:27.0] [27.0:0.1:28.0] S2=[36.0:0.2:38.0] S4=[45.5:1.0:46.5]	Boxes 3,4,5,7,8: Increase multiplier from Sigma-0=26.4 through Sigma-0 27.6 from 2.3 to 3.0 Box 6: Increase multiplier from S0=26.4 - S0=27.6 from 2.3 to 5.0
East of 49° E 1104_39,1104_49, 1105_30,1105_40, 1105_50 1104_19,1104_29, 1105_10,1105_20	Box 9 Box 10	41.0/34.0	35.0/1.0	None	goa_as.bins	
1105_52	stand alone	41.0/34.0	35.0/1.0	None	goa_as.bins	
Arabian Sea (1105) _41,_42,_51,_62 _21,_22,_31,_32 _00,_01,_02,_11,_12 _03,_04,_05, _13,_14,_15, _23,_24,_25 _33,_34,_35, _43,_44,_45, _53,_54,_55, _63,_64	Box 11 11a 11b 11c 11d 11e	41.0/34.0	35.0/1.0	None	goa_as.bins	51E–55E, 10N–16N

Table 3 lists for Region 2 the geographic sub-regions along with the 10° and 1° Marsden square filename identification; a definition for each "boxed" region; the ranges of acceptable limits for salinity and temperature; seasonal definitions; and density resolutions appropriate to each area.

4.2.1 Region 1: Description of Data Groupings

Region 1 data were divided into longitude strips, or latidude-longitude squares with similar theta-S properties (Table 2, Figure 4).

- The Persian Gulf area (Marsden Square 1204) had two sets of seasonal definitions: PG1 (Persian Gulf, Box 1) seasons were divided into two groups: May–November, and December–April. PG2 data were divided into April–November and December–March. These areas are labelled Box 1 and Box 2 in Figure 4. Boxes 3–6 were processed in longitude strips with the same seasonal divisions as Box 2.

- The Strait of Hormuz (Marsden Square 1205), Box 7 (Figure 4), data included profiles where the echo sounding depth was less than or equal to 200 m. Box 8 was defined using profiles where the echo sounding depth was greater than 200 m, and all profiles in the remaining 1° longitude strip. This was done to isolate the overflow water before it had equilibrated (at about 250 meters depth in the Gulf of Oman), where the theta-S relationship has an extreme salinity signature at depth, and a strong seasonal signal is present. The summer and winter seasons were defined as June–November, and December–May, respectively.

- The Gulf of Oman includes Box 9 and Box 10 (Figure 4), and data were processed using longitude strips. The remaining data in the Gulf of Oman and the northern Arabian Sea (Marsden Square 1206, Boxes 11a–j) were processed using the largest possible squares that could be processed in a reasonable amount of time.

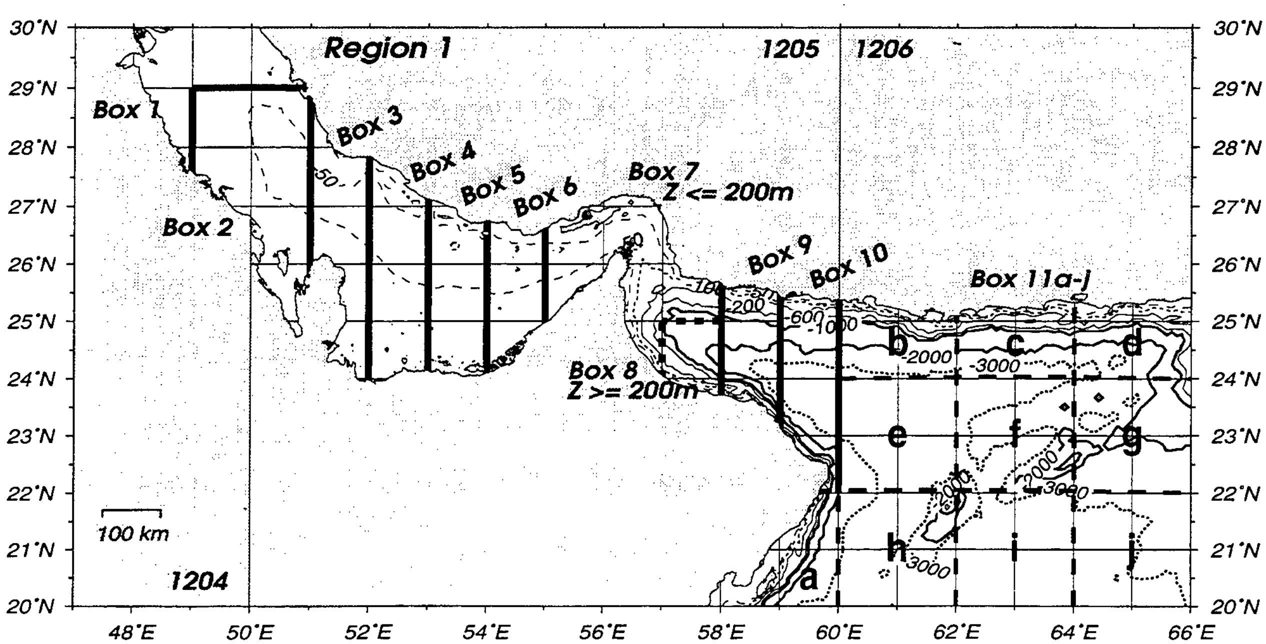


Figure 4. Chart of Region 1 with the geographical subdivisions and bathymetry.

4.2.2 Region 2: Description of Data Groupings

Within Region 2 area, groupings of 1° squares with similar theta-S profiles were combined (Figure 5, Table 3).

- The southern Red Sea area (Marsden Square 1104) was divided into a summer (July–November), and winter period (December–June). This area is bounded by 12° – 17° N, 42° – 43° E and is labelled Box 1 in Figure 5.

- The BAM Strait (Box 2) also had a summer and winter division. Summer was defined as June–October, and Winter defined as November–June. In the BAM Strait the geographic constraints were enough to isolate the unequilibrated overflow water profiles, and no depth criterion was necessary. This area was bounded by everything north of 12° and 43° – 44° E.

- The Gulf of Aden area was split into two geographic areas: West of 49° E (Boxes 3–8), and East of 49° E (Boxes 9–10), with no seasonal divisions. This was done to isolate the profiles with a strong overflow water signature (west of 49° E). Each geographic box had approximately four 1° squares (Figure 5, Table 3).

- The western Arabian Sea data (represented by Marsden Square number 1105, Boxes 11a-e) were combined in the largest possible squares that could be processed in a reasonable amount of time.

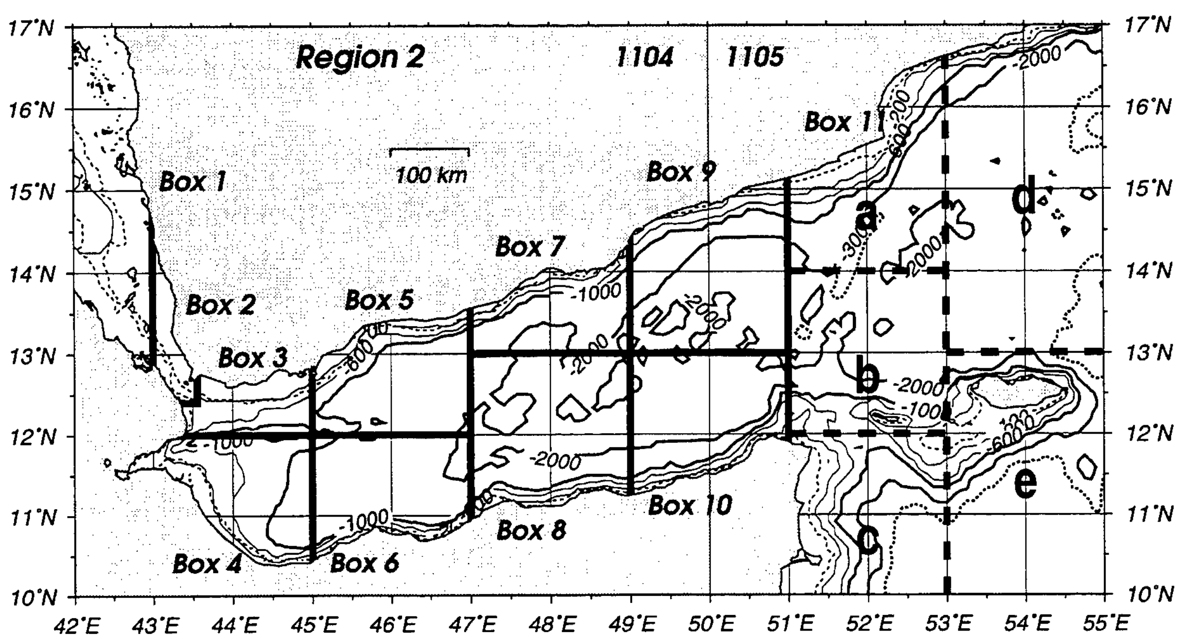


Figure 5. Chart of Region 2 shown with the geographical subdivisions and bathymetry.

Figure 6. QC results from a standard pass through the data:

a) Chart showing the location of the data analyzed.
TSn represents the number of total stations for Region 2, Box 1105_52.
TSn/b represents the number of stations with bad profile data.
GSc represents the number of good scans (data points) in the defined box.
BSc represents the number of bad scans.

b) Sigma-0 plotted vs. depth. The gray represents all the data for Region 2, Box 1105_52. The black circles show which values were eliminated.

c) Temperature (squares) and salinity (circles) plotted vs. depth. The gray represents the resulting QC data, the black circles/squares show which values were eliminated.

d) Theta-S diagram from Region 2, Box 1105_52 mapped with density bin contours used in the statistical fit. The solid contours are theta relative to sigma-0, the dotted lines are relative to sigma-2, and the dashed lines are relative to sigma-4. (These sigma contours represent the actual sigma bins used to subdivide the data in this region.) The solid black squares depict the mean theta-S pair for each bin. The thin solid lines going through the mean approximates the mean theta-S curve for the area. The lines on either side of the mean define the 2.0 standard deviation envelope.

e) Theta-S diagram with density contours. The black points represent the data remaining after the statistical checking procedure was applied to the data. Gray indicates the points eliminated which lie outside the 2.3 standard deviation envelope. The different symbols indicate the depth regimes which determine the reference level associated with each point. The solid white squares depict the mean theta-S pair for each bin.

The QC procedure was applied twice to each defined region. This plot represents the first pass through the data.

Figure 7. QC results of a case where the standard deviation multiplier was increased for sigma-0 26.4 through 27.6, from 2.3 to 3.0.

a) Chart showing the location of the data analyzed.

b) Sigma-0 plotted vs. depth for Region 1, Box 11i.

c) Temperature (squares) and salinity (circles) vs. depth

d) Theta-S diagram from Region 1, Box 11i mapped with density bin contours.

e) Theta-S diagram with density contours.

The QC procedure was applied twice to each defined region. This plot represents the first pass through the data.

Figure 6 - 1105_52

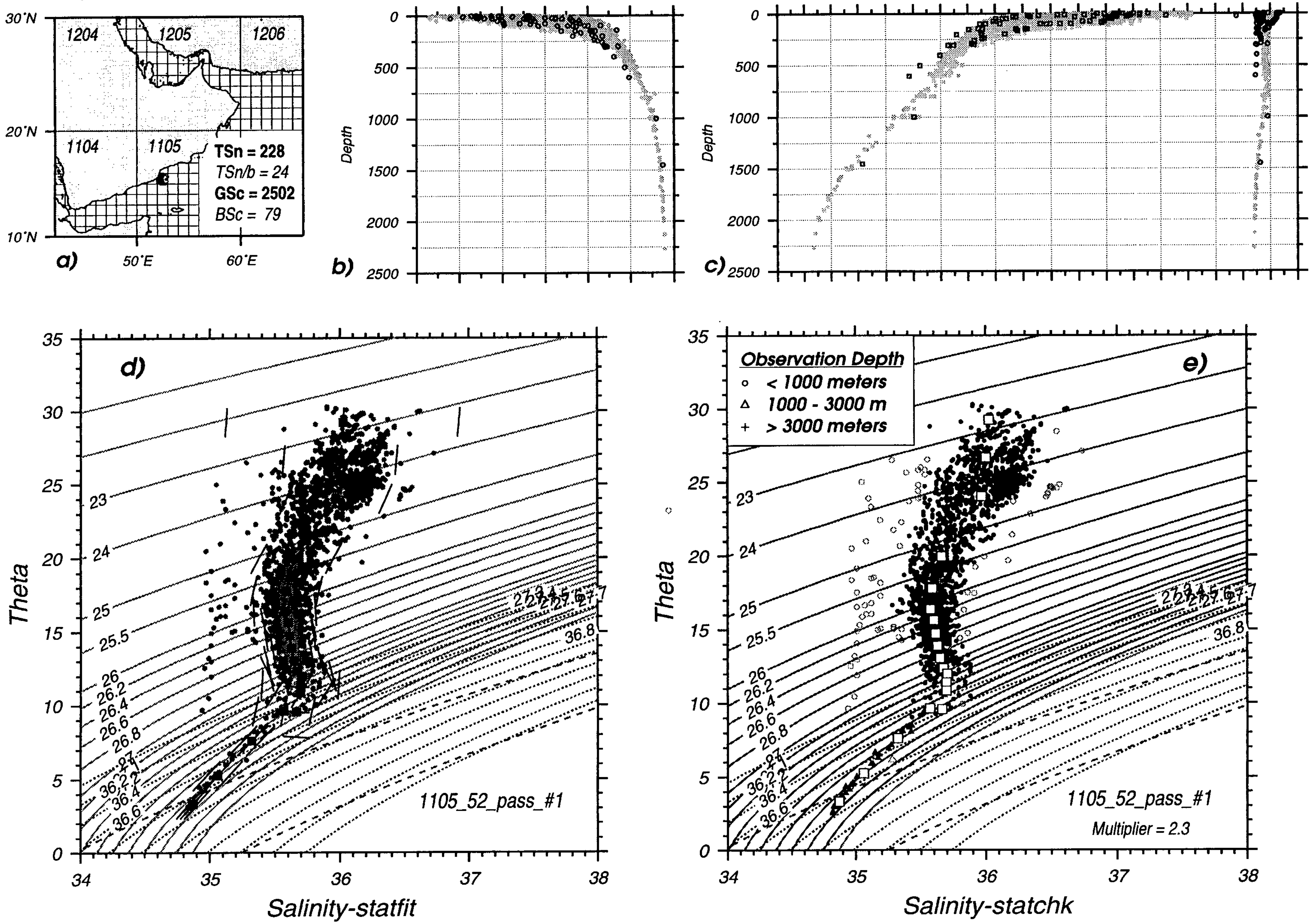
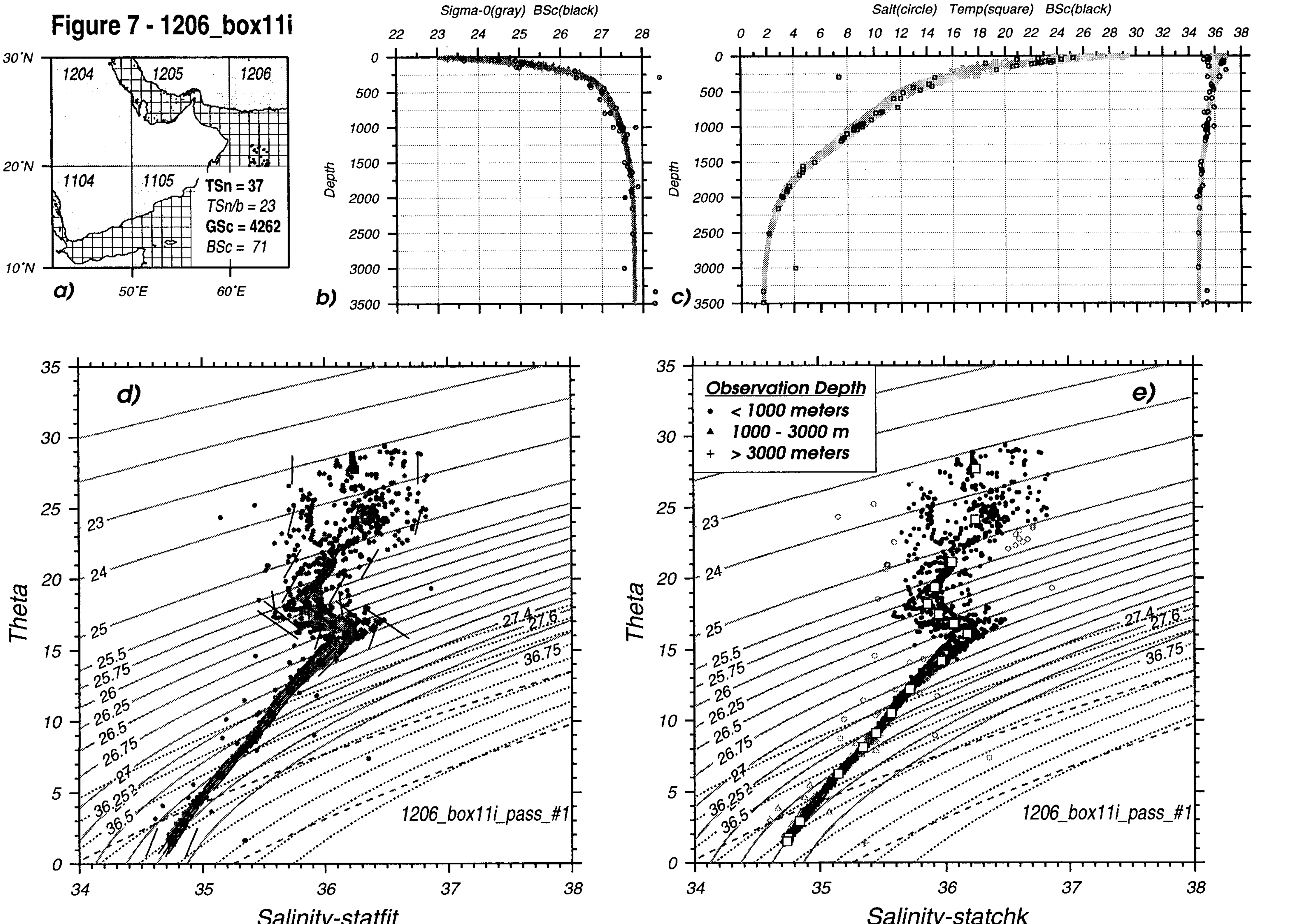


Figure 7 - 1206_box11i



4.3 Visual Scan

During our visual scan of the quality controlled data, two stations (out of 7040 profiles), were physically edited out. Data points on these profiles lay outside the accepted temperature and salinity values below the thermocline, but not in the surface waters. For this reason, these profiles were not eliminated in the range checking. The data within these profiles biased the mean and standard deviation within density bins, and were not able to be eliminated using the statistical checking method. The original data from this box were regrouped, the two profiles eliminated, and rerun through the statistical checking procedure.

4.4 The Final Quality Controlled Data Set

The procedure outlined above in Section 4 was applied to each "boxed" area twice. For the first pass, 1.97% of the scans, representing 2.91% of the profiles were eliminated.

The second pass, the resultant data from the first pass were used as input, the statistics were recalculated and the elimination process was repeated. An additional 1.58% of the scans, representing 0.91% of the profiles, failed to meet the theta-S criterion. Table 4 summarizes the number of profiles and scans eliminated during the entire QC process for each 10° Marsden square.

Table 4. Number of Profiles (upper) and Scans (lower) in Data Set

	Region 2		Region 1			
Marsden Square #	1104	1105	1204	1205	1206	Total Profiles
Sum Original	2,588	1,593	451	1,746	662	7,040
Sum After QC	2,531	1,555	410	1,642	619	**6,757**
Difference	57	38	41	104	43	283

	Region 2		Region 1			
Marsden Square #	1104	1105	1204	1205	1206	Total Scans
Sum Original	124,618	76,693	3,731	289,103	413,343	907,488
Sum After QC	121,088	73,720	3,388	277,715	399,660	**875,571**
Difference	3,530	2,973	343	11,338	13,683	31,917

The bar graph (Figure 8) shows the vertical distribution of the data before QC (black) and after QC (gray). The QC procedure has not changed the distribution of the data. Figure 9 shows the yearly distribution of the data before QC (black) and after QC (gray).

Overall, the quality control procedure reduced the total data set by **3.5%** of the data scans, representing 4.0% of the profiles. The final data set consists of 875,571 scans (6757 profiles).

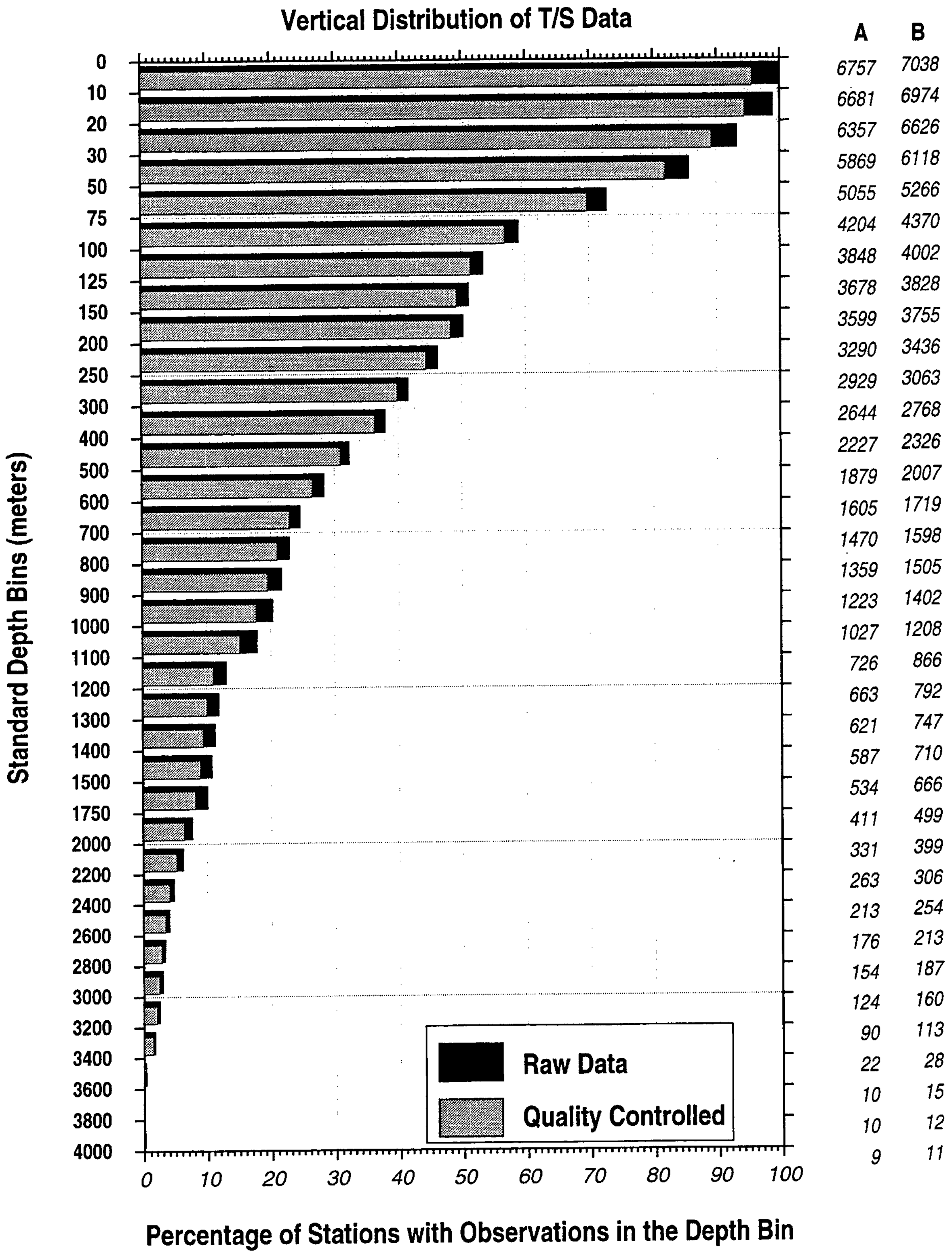


Figure 8. Vertical distribution of the data before QC (black), and after QC (gray). Column A shows the number of profiles with observations after QC. Column B shows the number of profiles in the original data set.

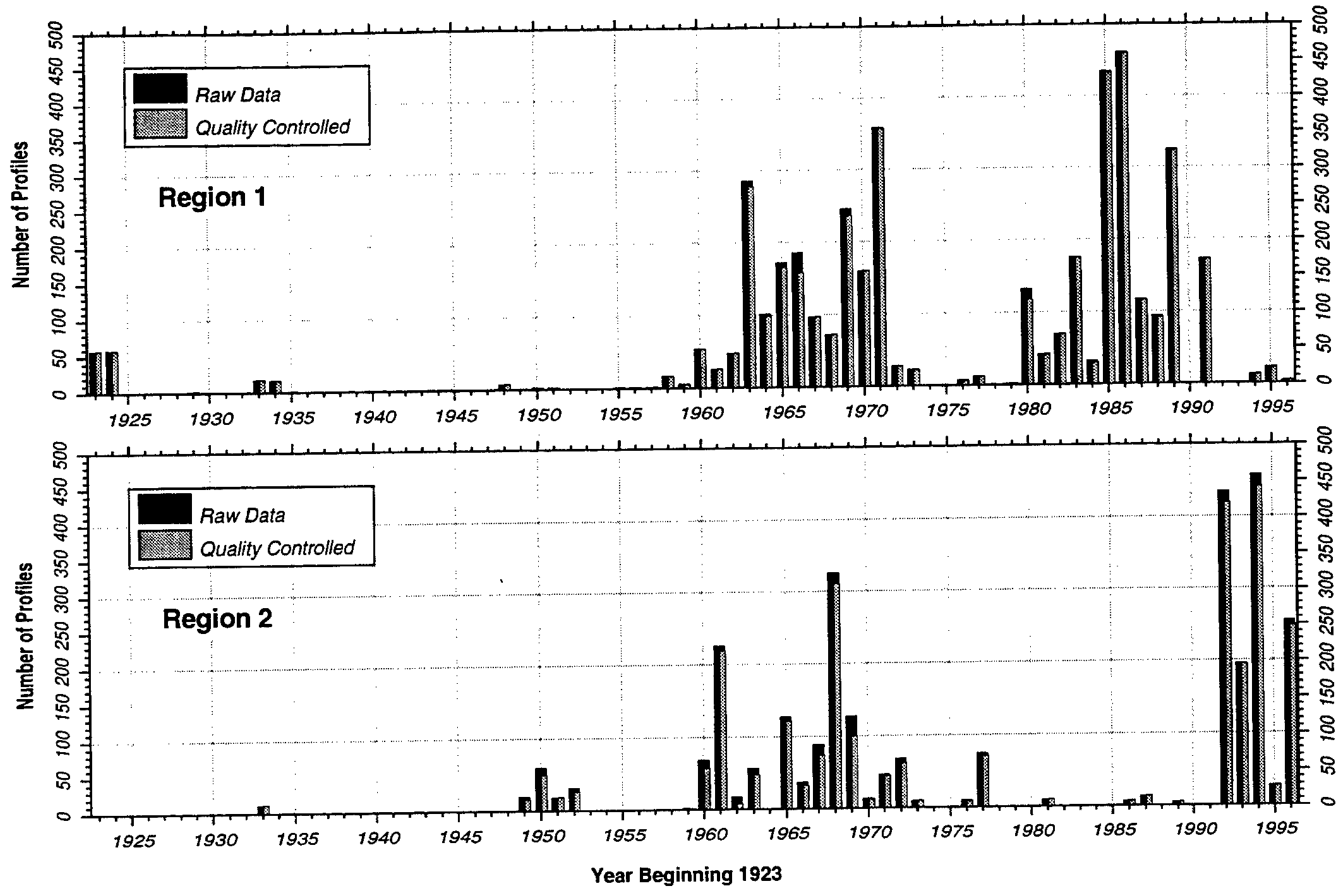


Figure 9: Yearly distribution of the data before QC (black), and after QC (gray).

5. Description of Data Presentation

The final, quality controlled hydrographic data are shown in the form of theta-S diagrams (total and by season), with sigma-0 density mapped onto the theta-S diagram. The seasonal breakdowns are listed in Table 5. In addition, profiles are plotted of temperature and salinity vs. depth. An orientation map showing the locations of the profiles is also provided. The number in the upper right-hand corner of the theta-S plots represents the number of profiles plotted. The plots represent all of the data from each "boxed" area.

The geographical distribution of the data as a function of month is shown for Regions 1 and 2 in Figures 10 and 11, respectively.

Table 5. Seasonal Definitions for Data Presentation

Winter	December	January	February
Spring	March	April	May
Summer	June	July	August
Fall	September	October	November

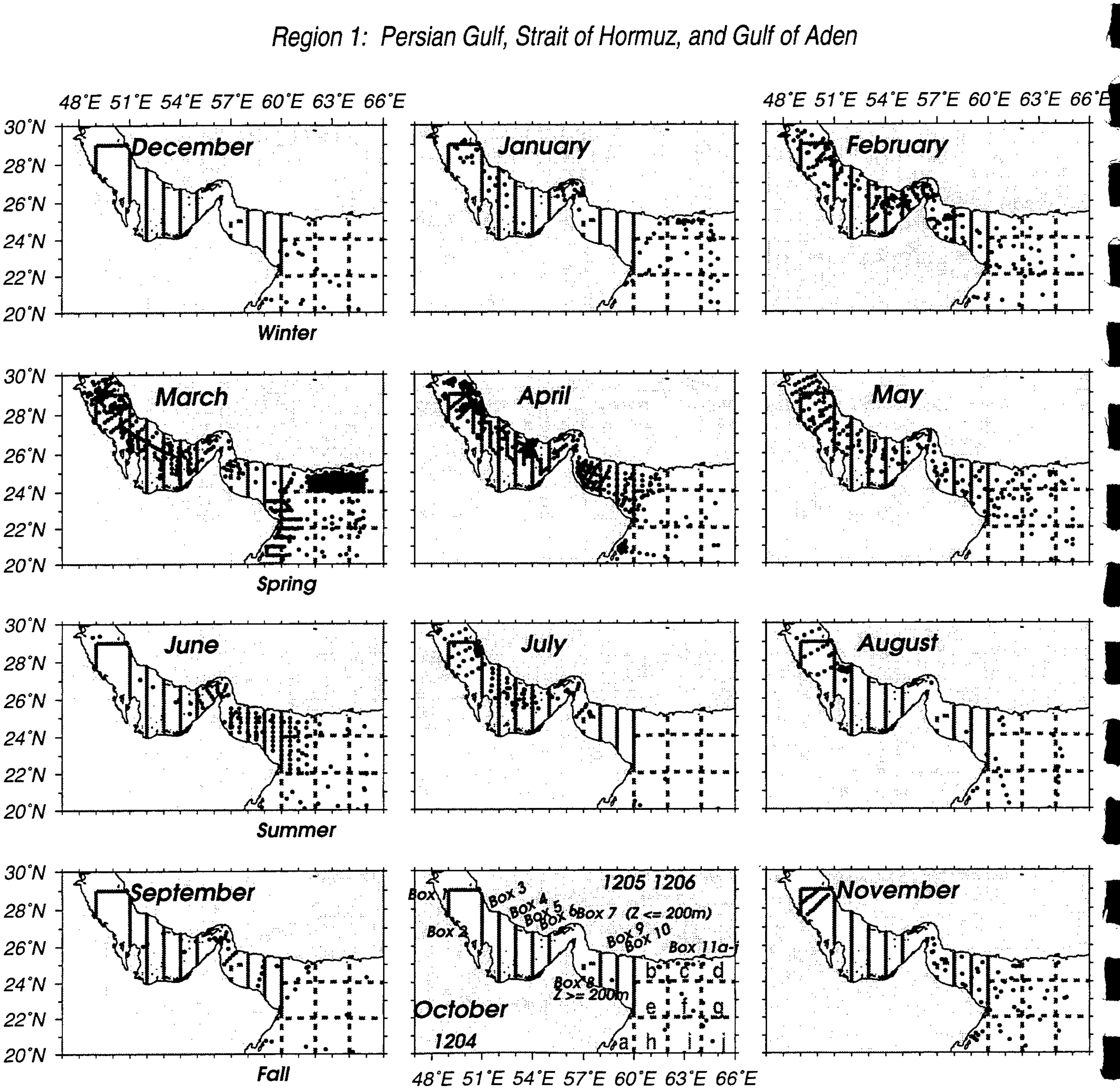


Figure 10. Geographical distribution of data for Region 1 as a function of month. The gray lines denote "boxed" regions. The seasonal definitions (Table 5) are grouped horizontally.

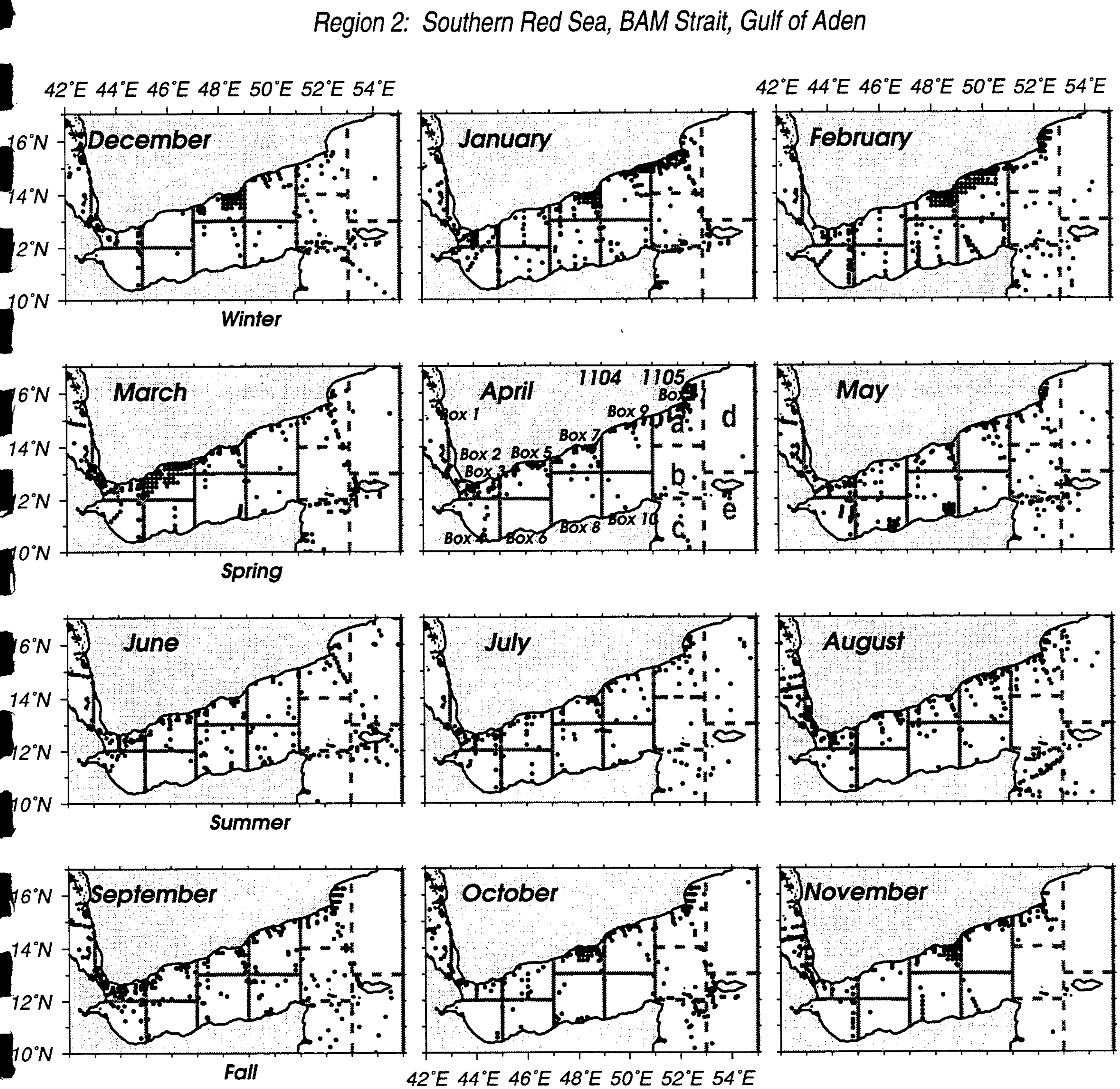


Figure 11. Geographical distribution of data for Region 2 as a function of month. The gray lines denote "boxed" regions. The seasonal definitions (Table 5) are grouped horizontally.

6. Acknowledgments

We gratefully acknowledge this study by the Office of Naval Research under Grant N00014-95-1-0284.

7. References

Curry, R. G., 1996. Hydrobase – A database of hydrographic stations and tools for climatological analysis, *Woods Hole Oceanographic Institution Tech. Rep.*, WHOI-96-01, 44 pp., Woods Hole Oceanog. Inst., Woods Hole, Mass.

Levitus, S., and T. Boyer, 1994. World Ocean Atlas 1994, Vol 4: Temperature. NOAA Atlas NESDIS4. U.S. Government Printing Office, Washington, D.C., 150 pp.

Lozier, M. Susan, W. B. Owens, and R. G. Curry, 1996. The Climatology of the North Atlantic, *Prog. in Oceanog.* 36, 1-44.

Privett, D. W., 1959. Monthly charts of evaporation from the North Indian Ocean, including the Red Sea and the Persian Gulf. *Q. J. Roy. Meteor. Soc.*, **85**, 424–428.

Rochford, D. J., 1964. Salinity maxima in the upper 1000 meters of the north Indian Ocean. *Aust. J. Mar. Freshw. Res.*, **15**, 1-24.

Wyrtki, K., 1971. Oceanographic atlas of the International Indian Ocean Expedition, National Science Foundation, Washington, D.C., 531 pp.

8. Data Presentation for Region 1

Figure 12 - 1204_box1

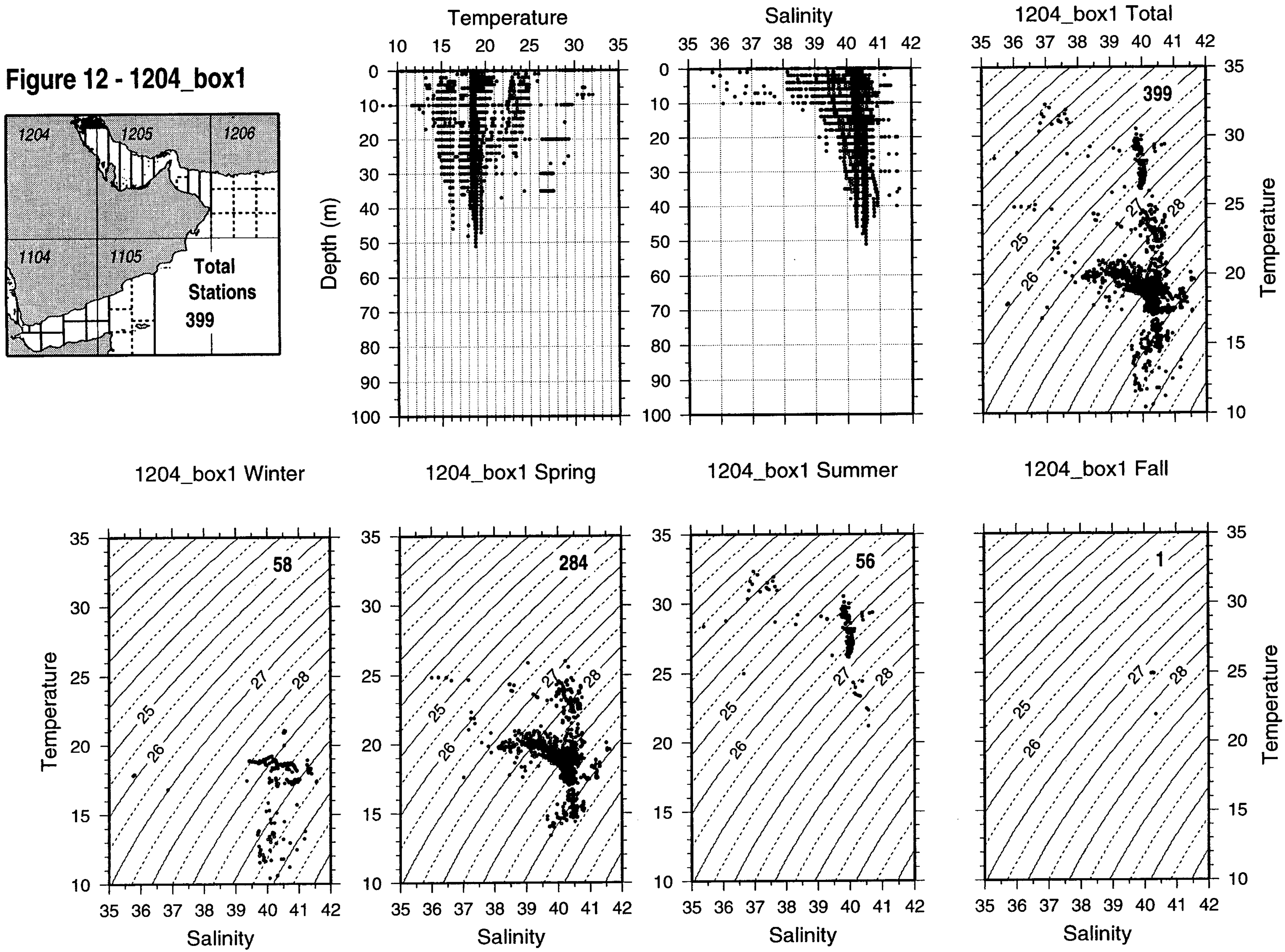


Figure 13 - 1204_box2

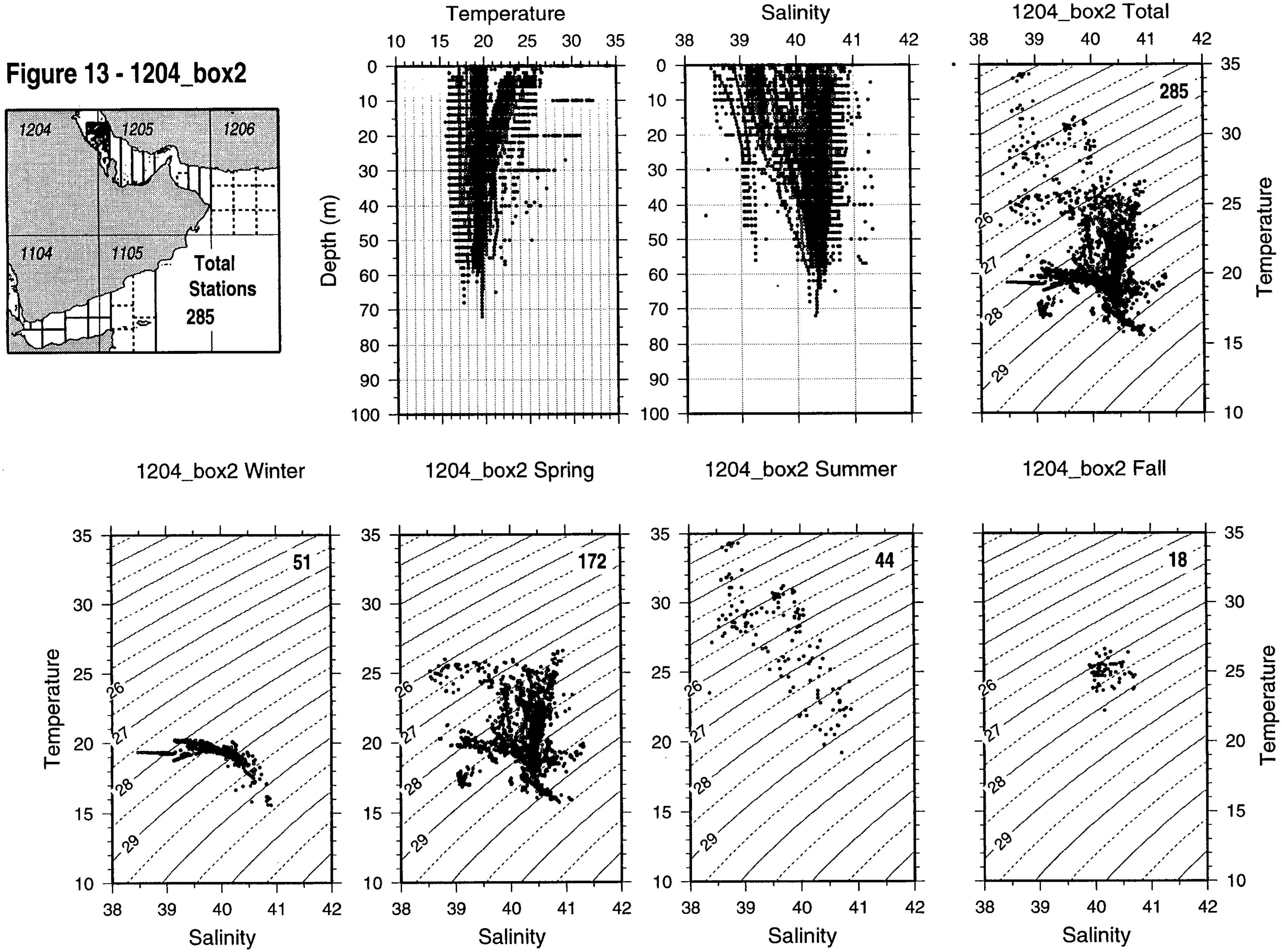


Figure 14 - 1205_box3

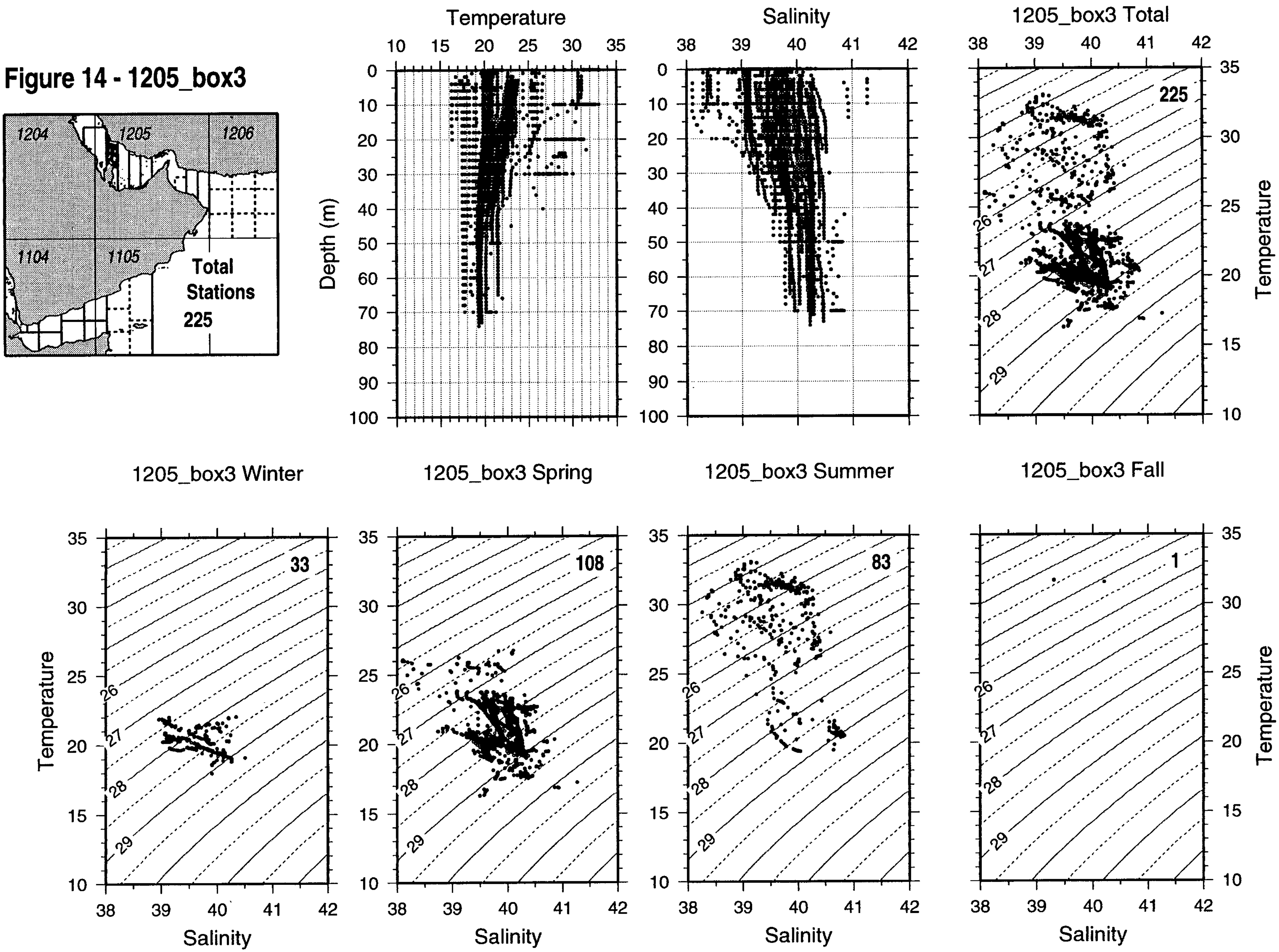


Figure 15 - 1205_box4

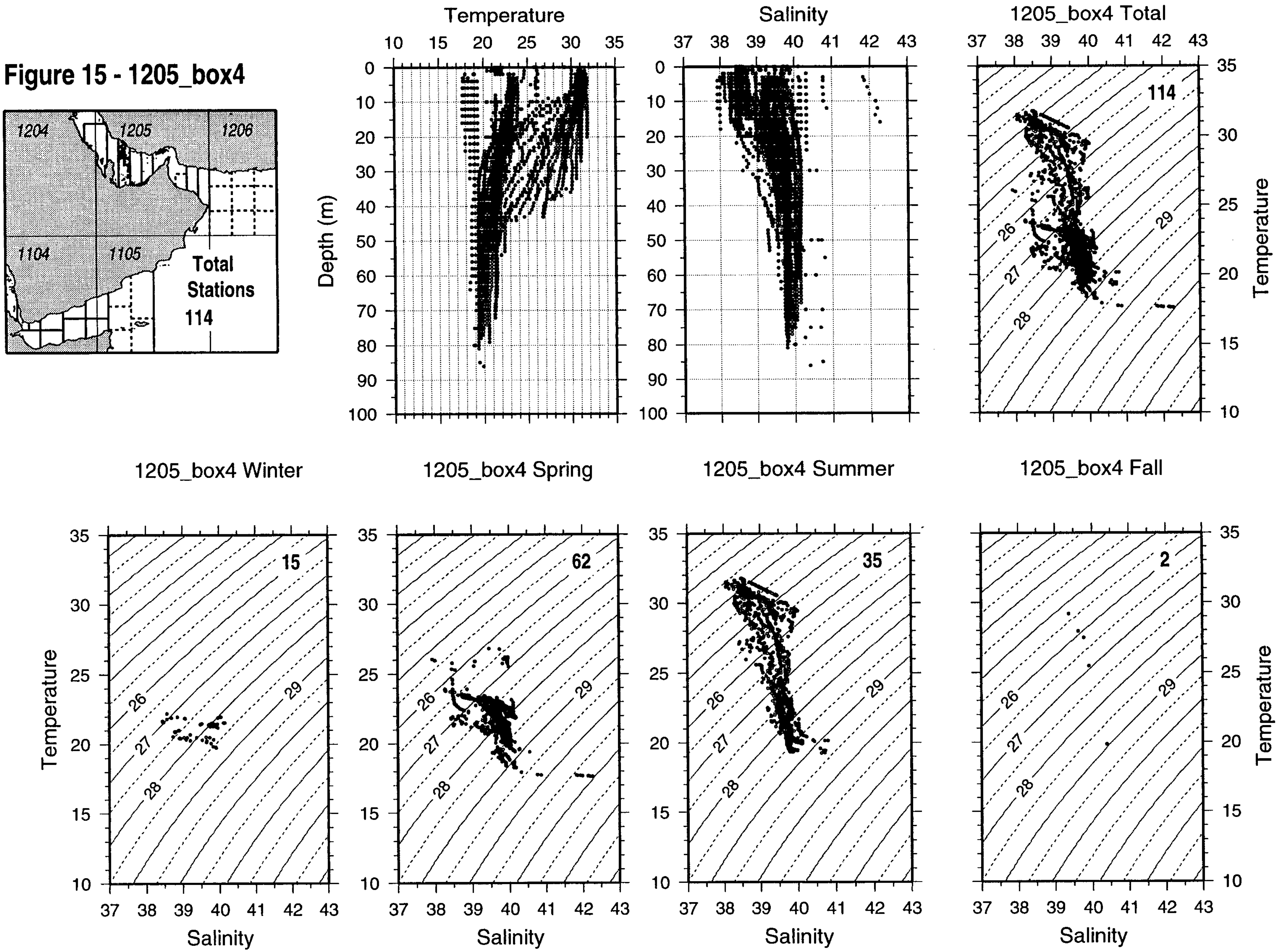


Figure 16 - 1205_box5

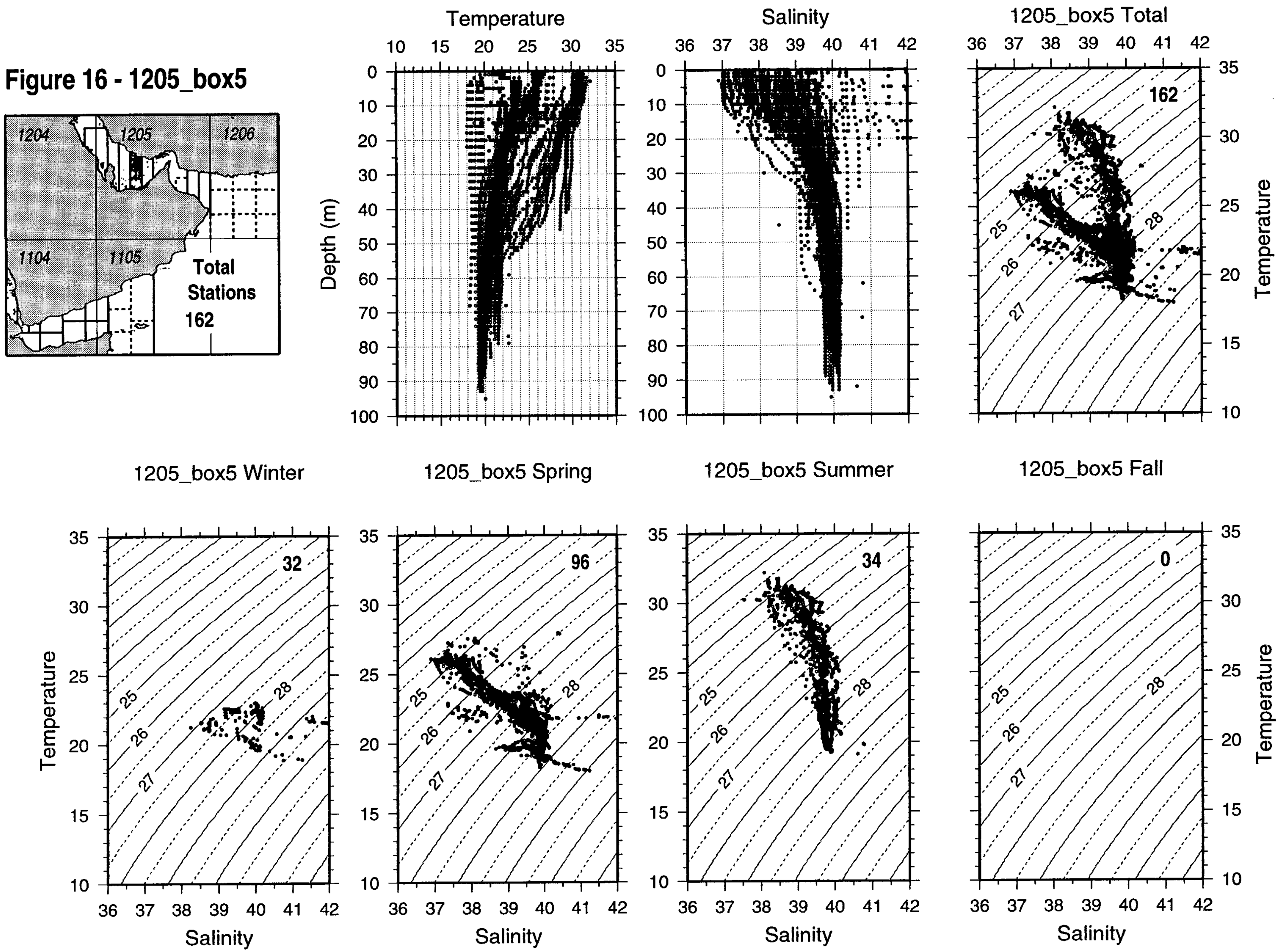


Figure 17 - 1205_box6

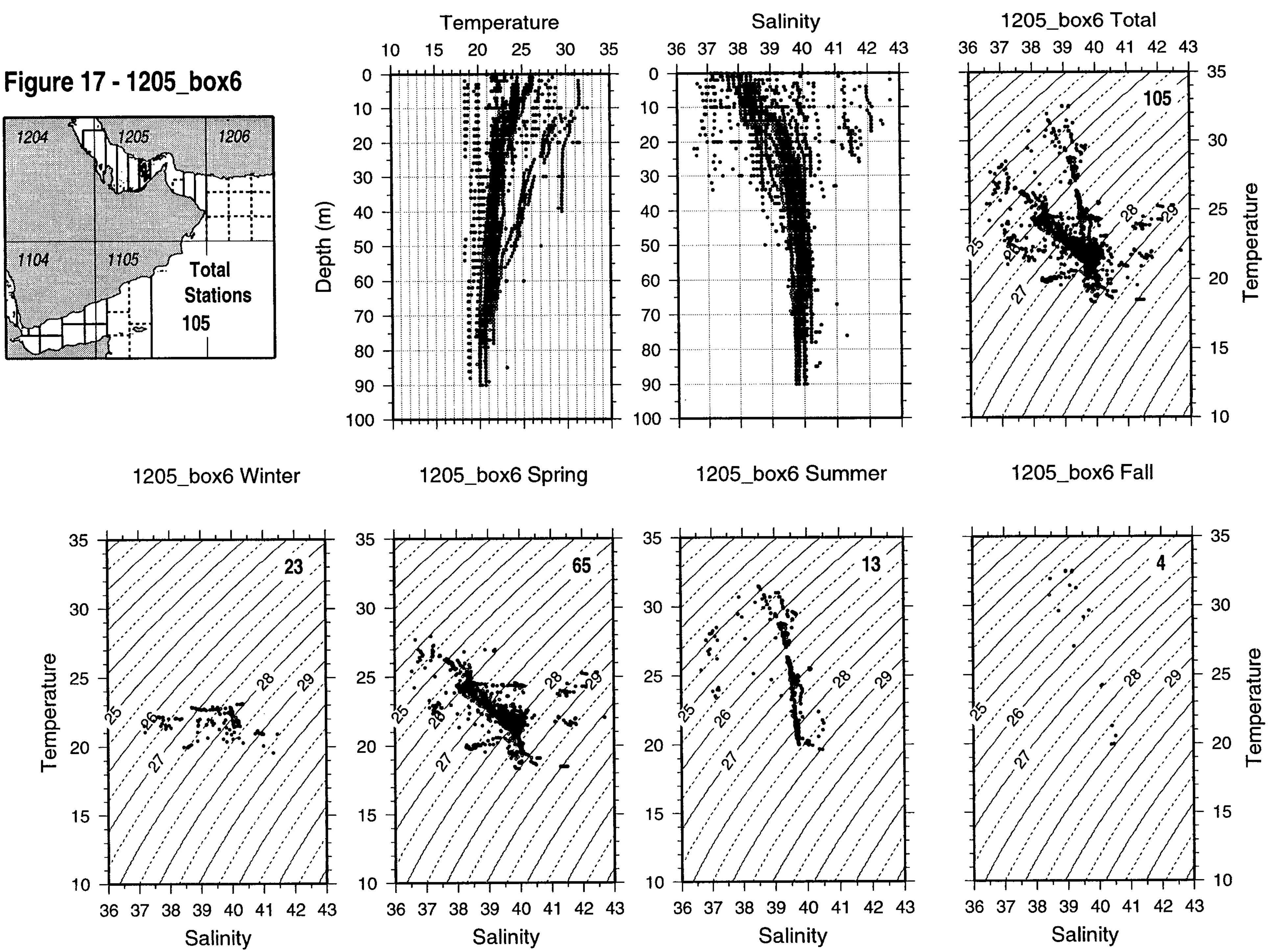


Figure 18 - 1205_box7

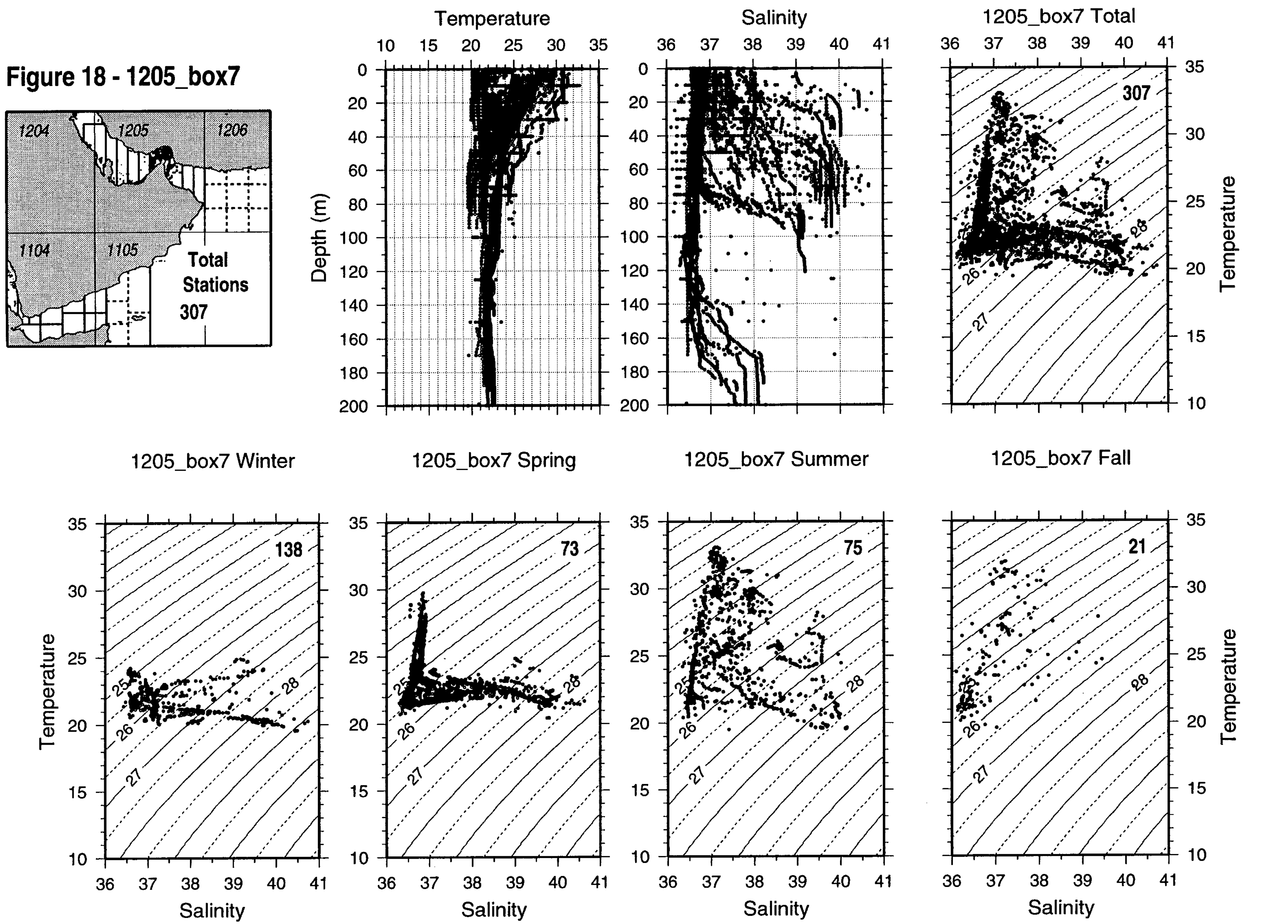


Figure 19 - 1205_box8

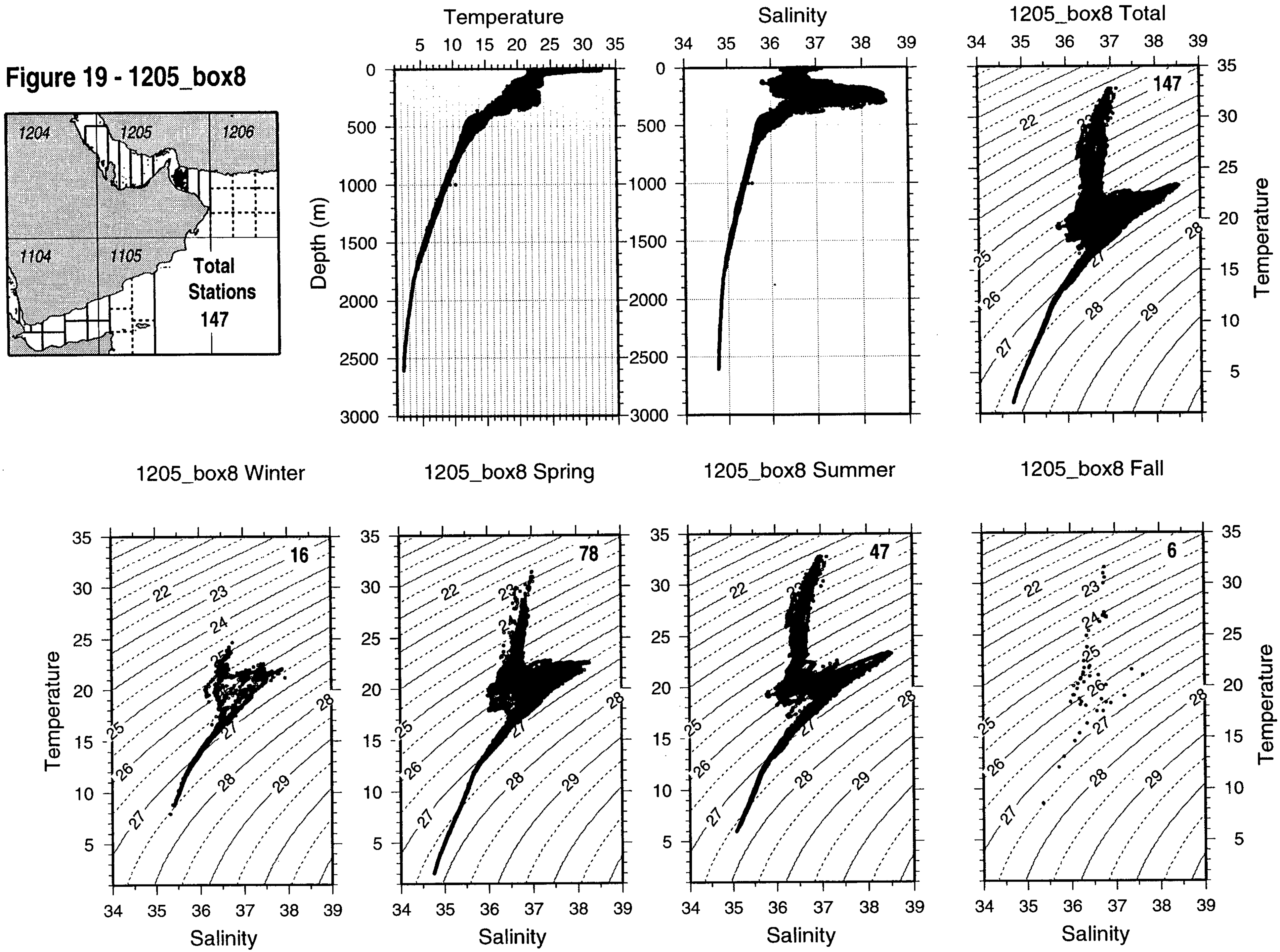


Figure 20 - 1205_box9

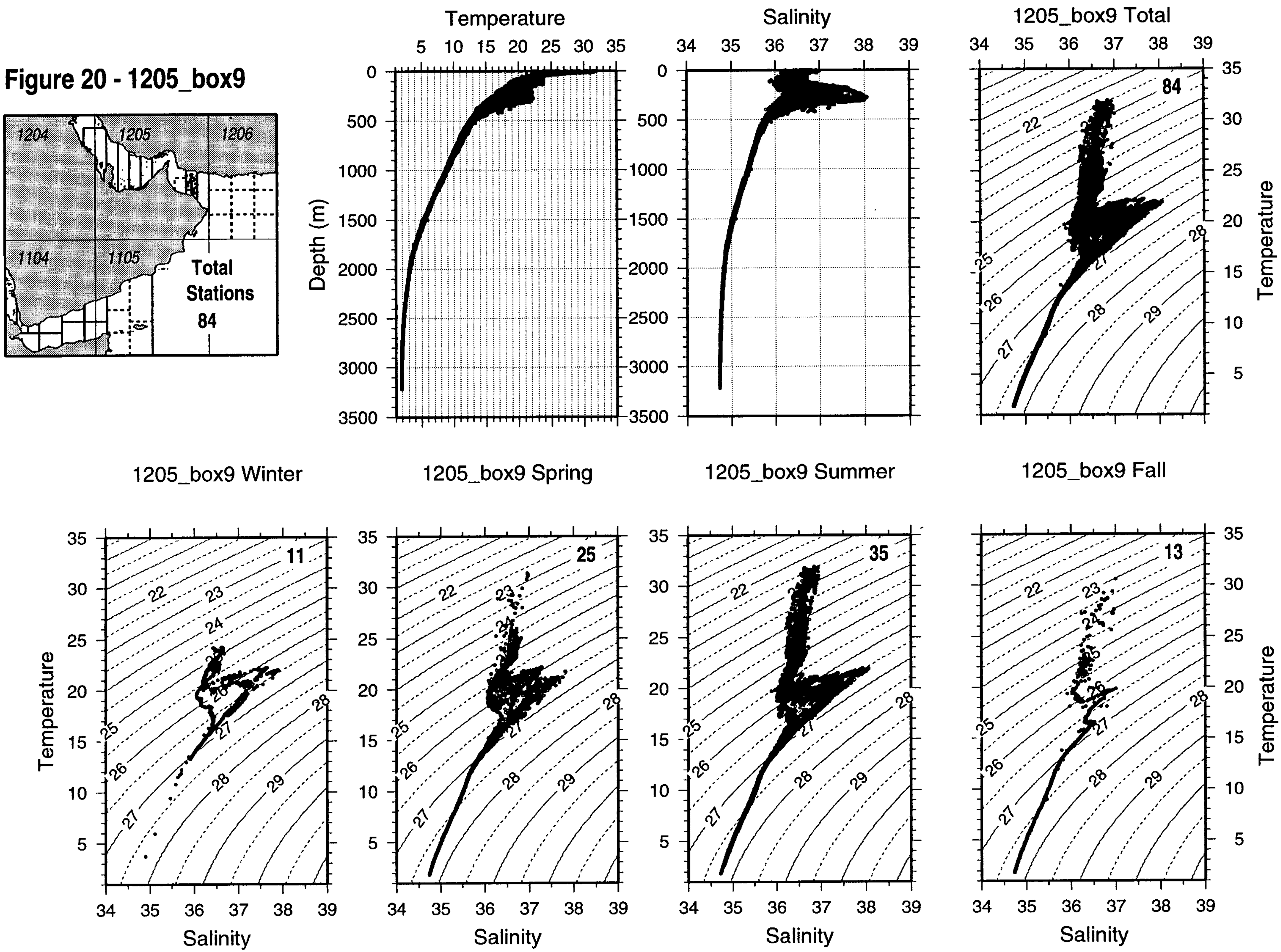


Figure 21 - 1205_box10

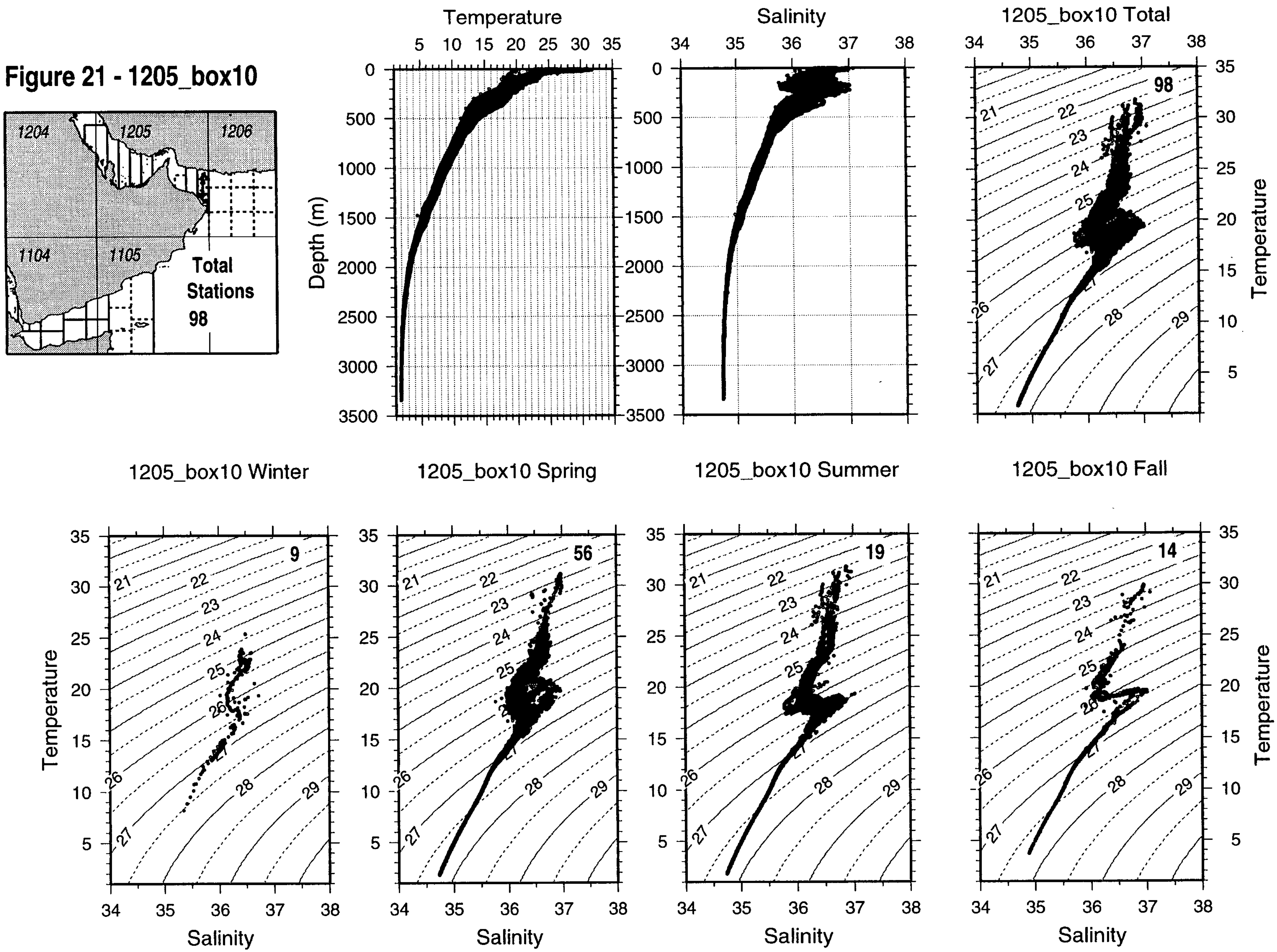


Figure 22 - 1205_box11a

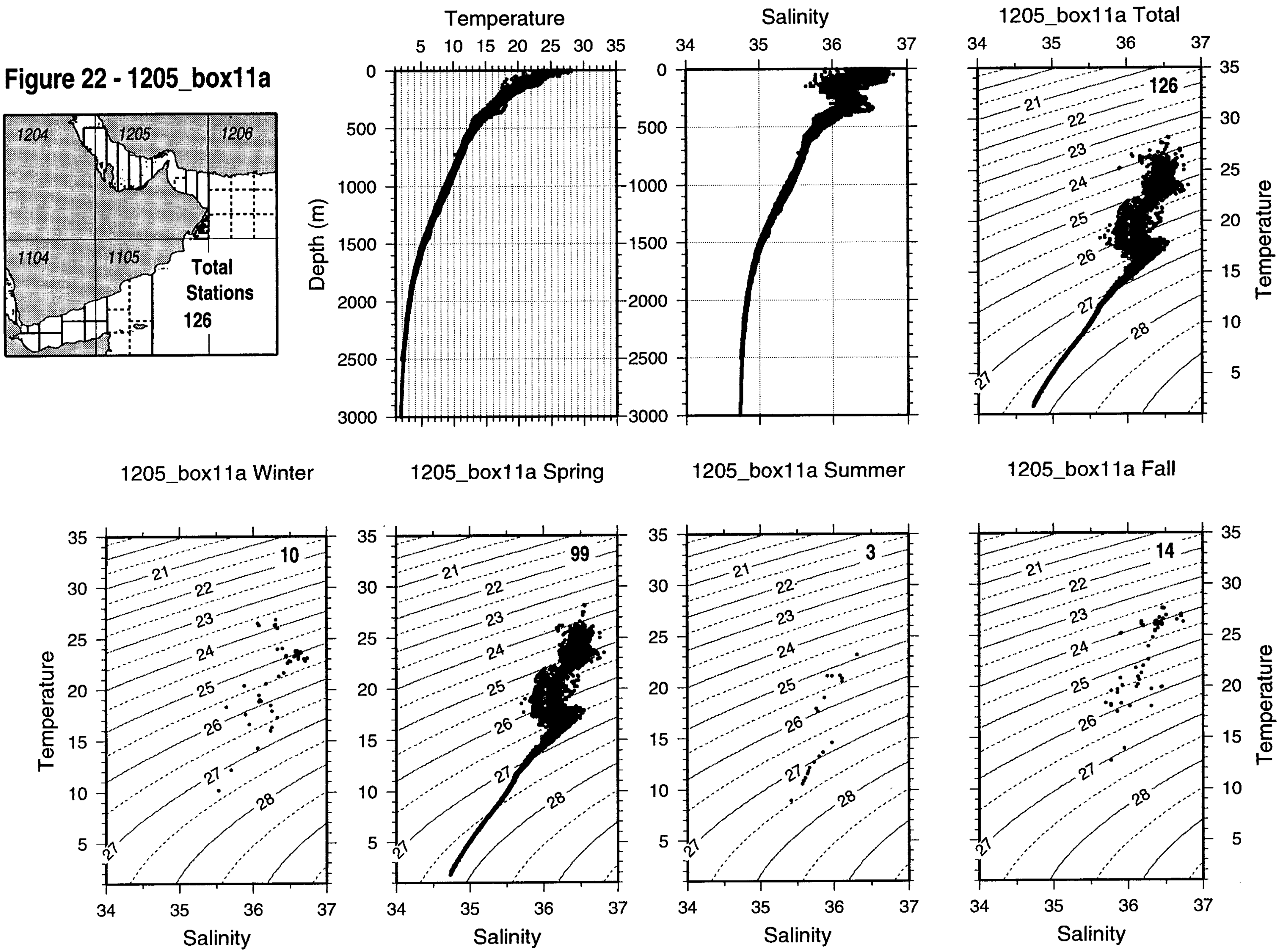


Figure 23 - 1206_box11b

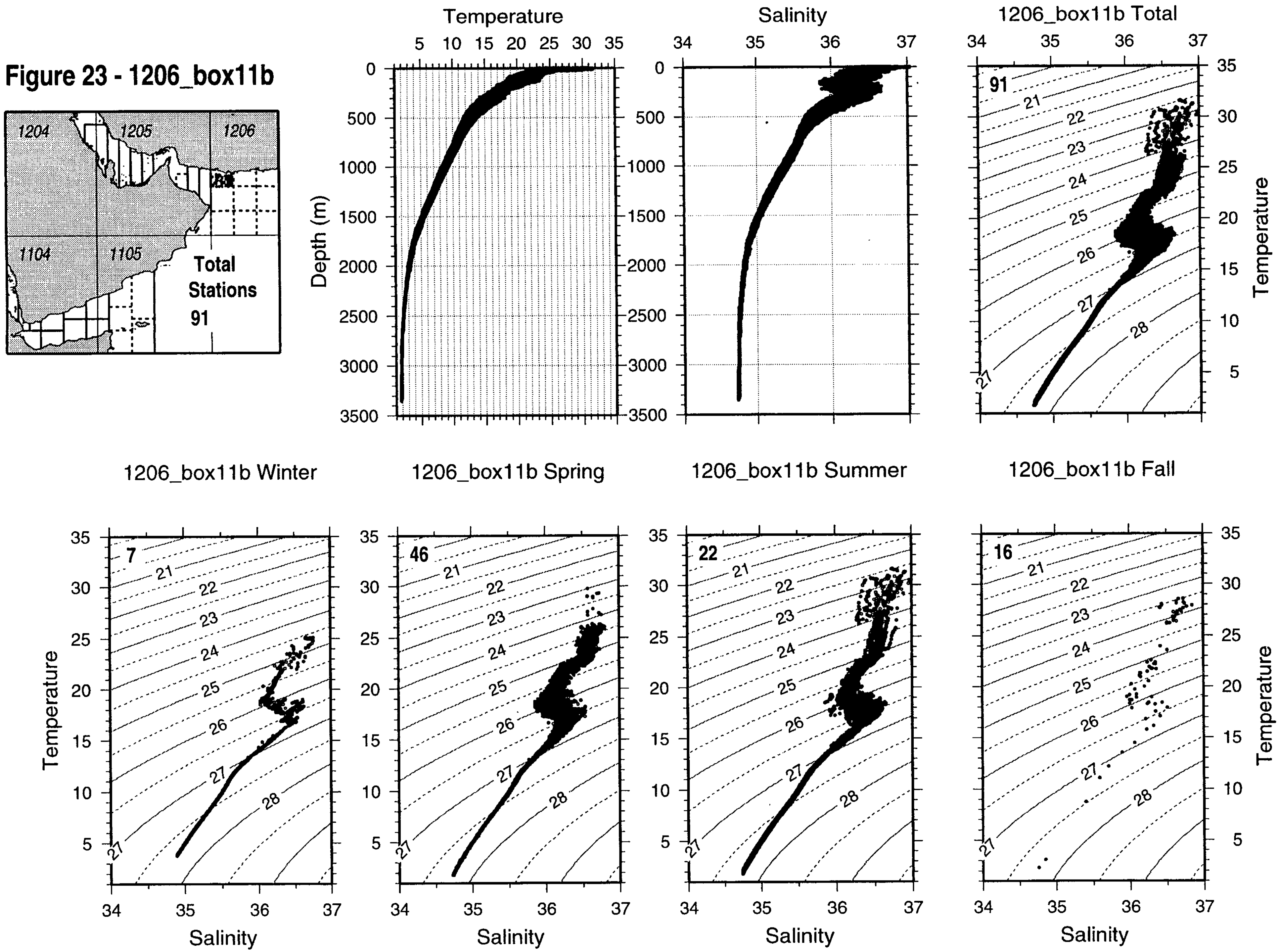


Figure 24 - 1206_box11c

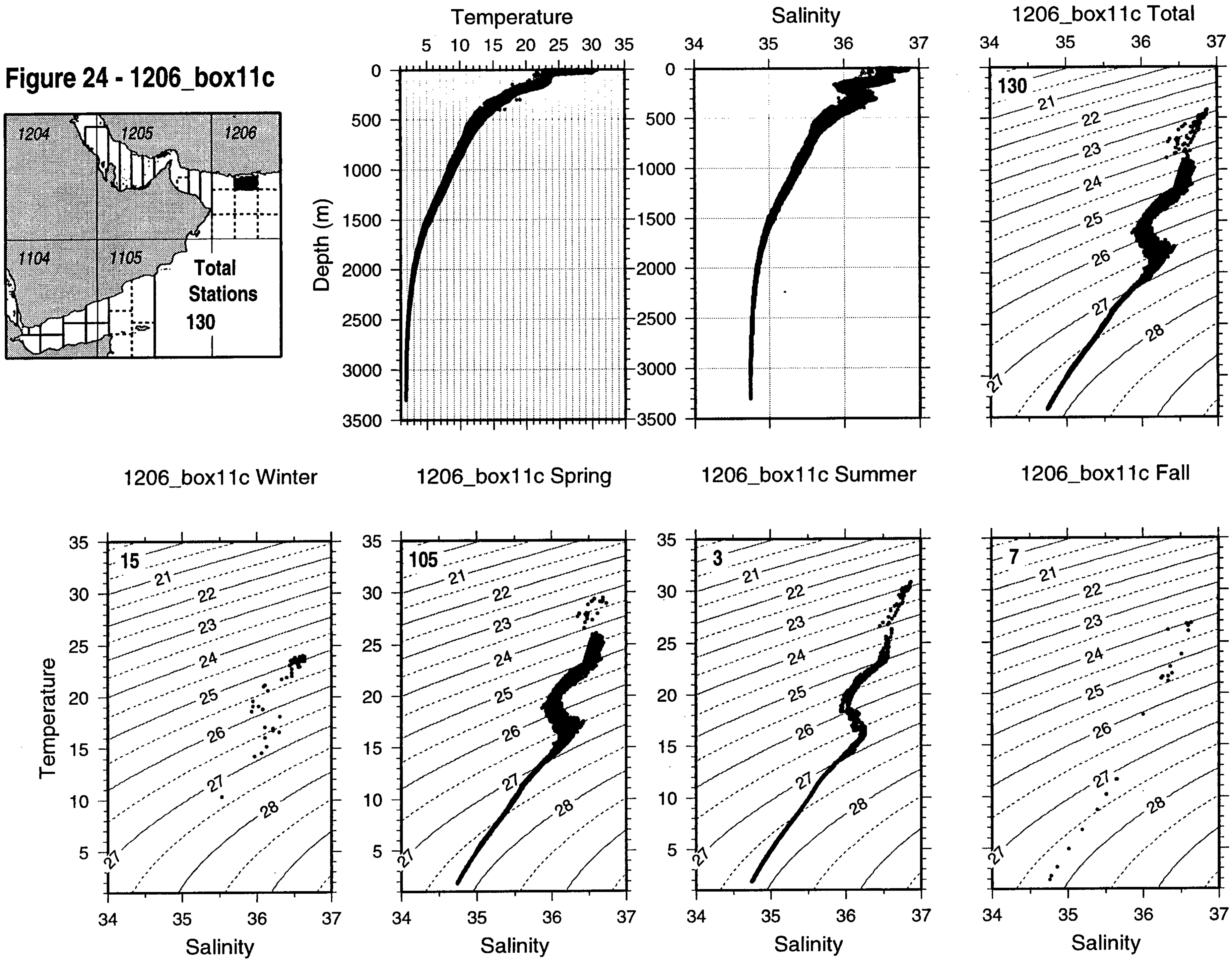


Figure 25 - 1206_box11d

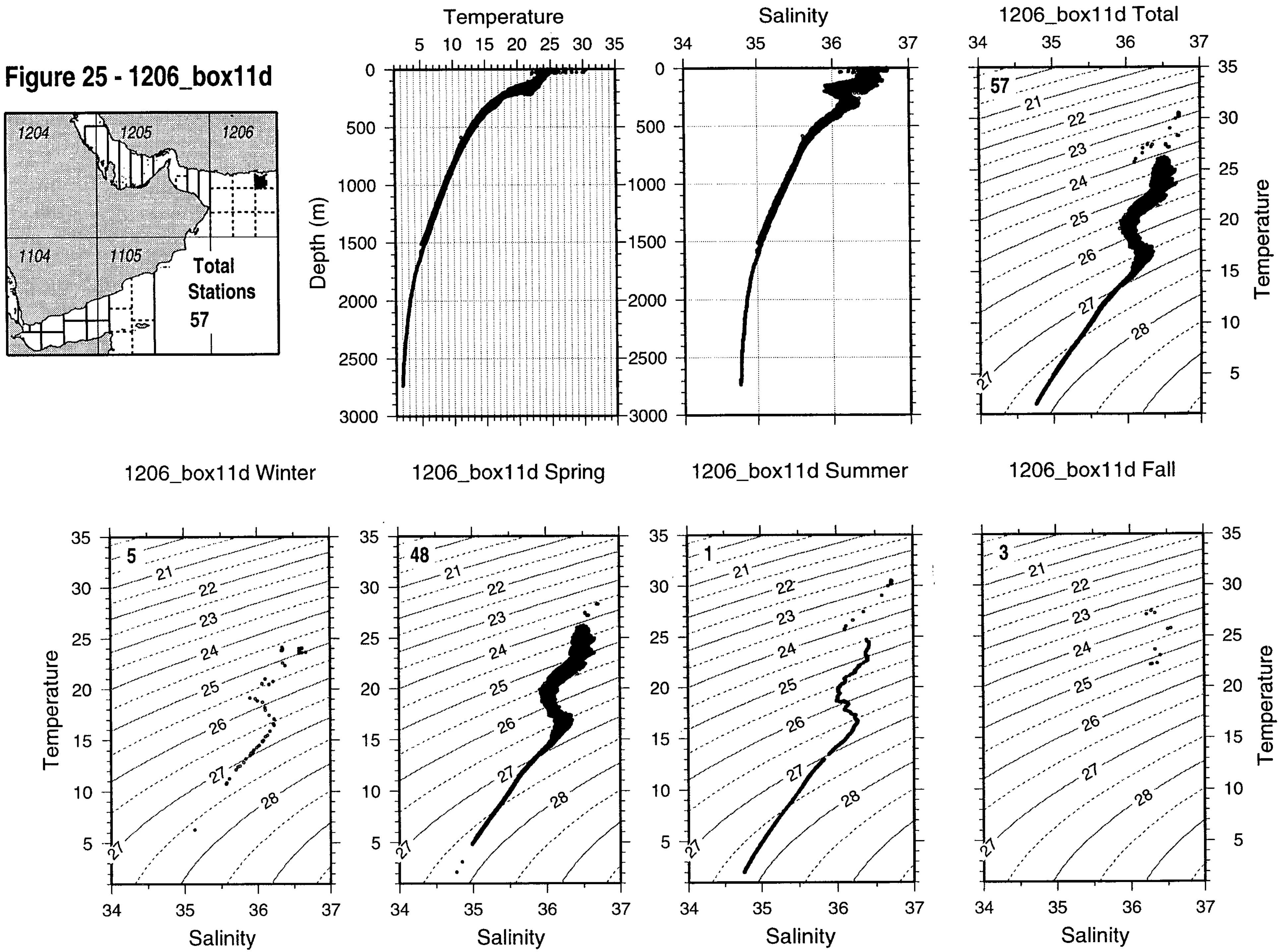


Figure 26 - 1206_box11e

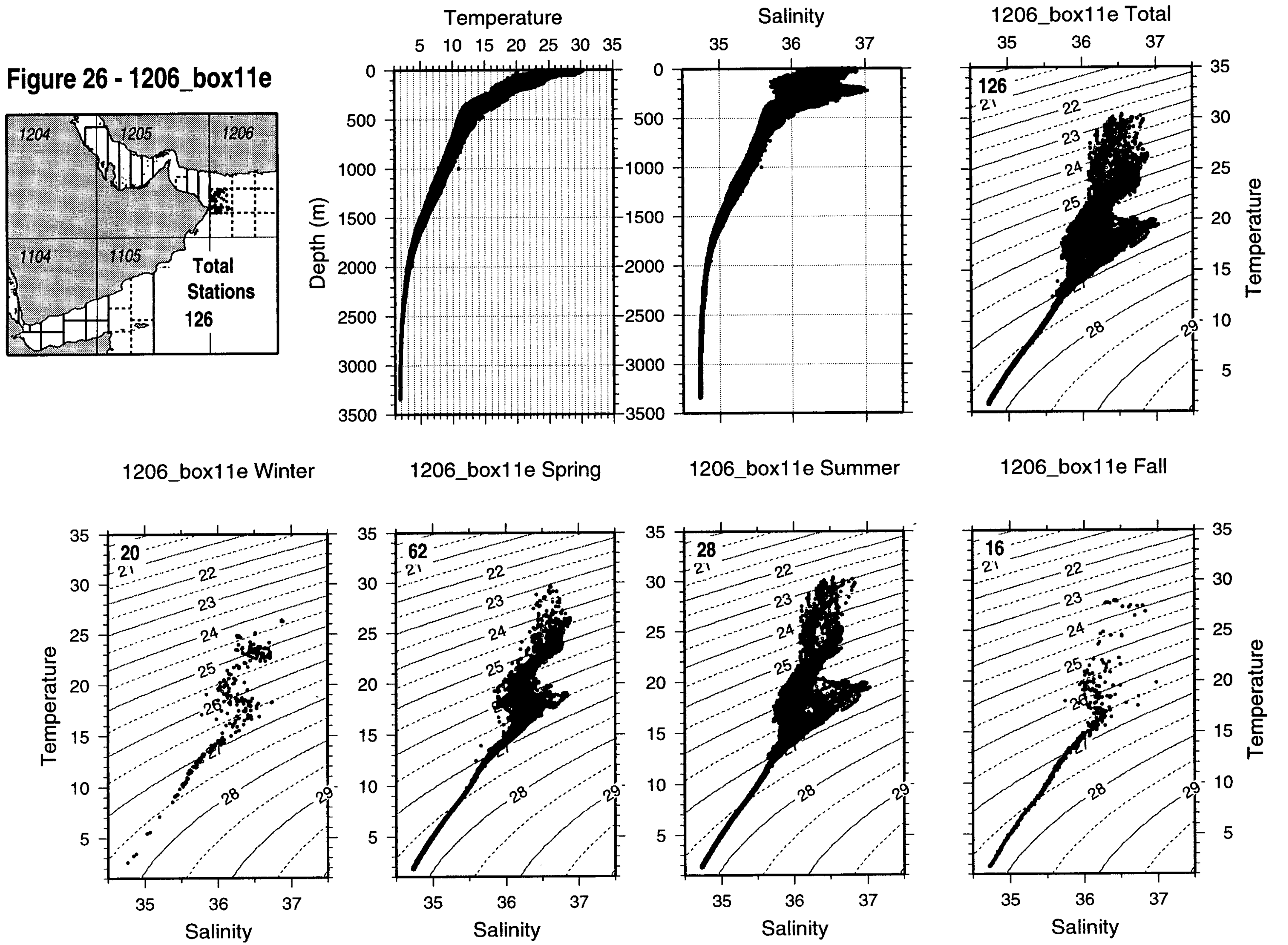


Figure 27 - 1206_box11f

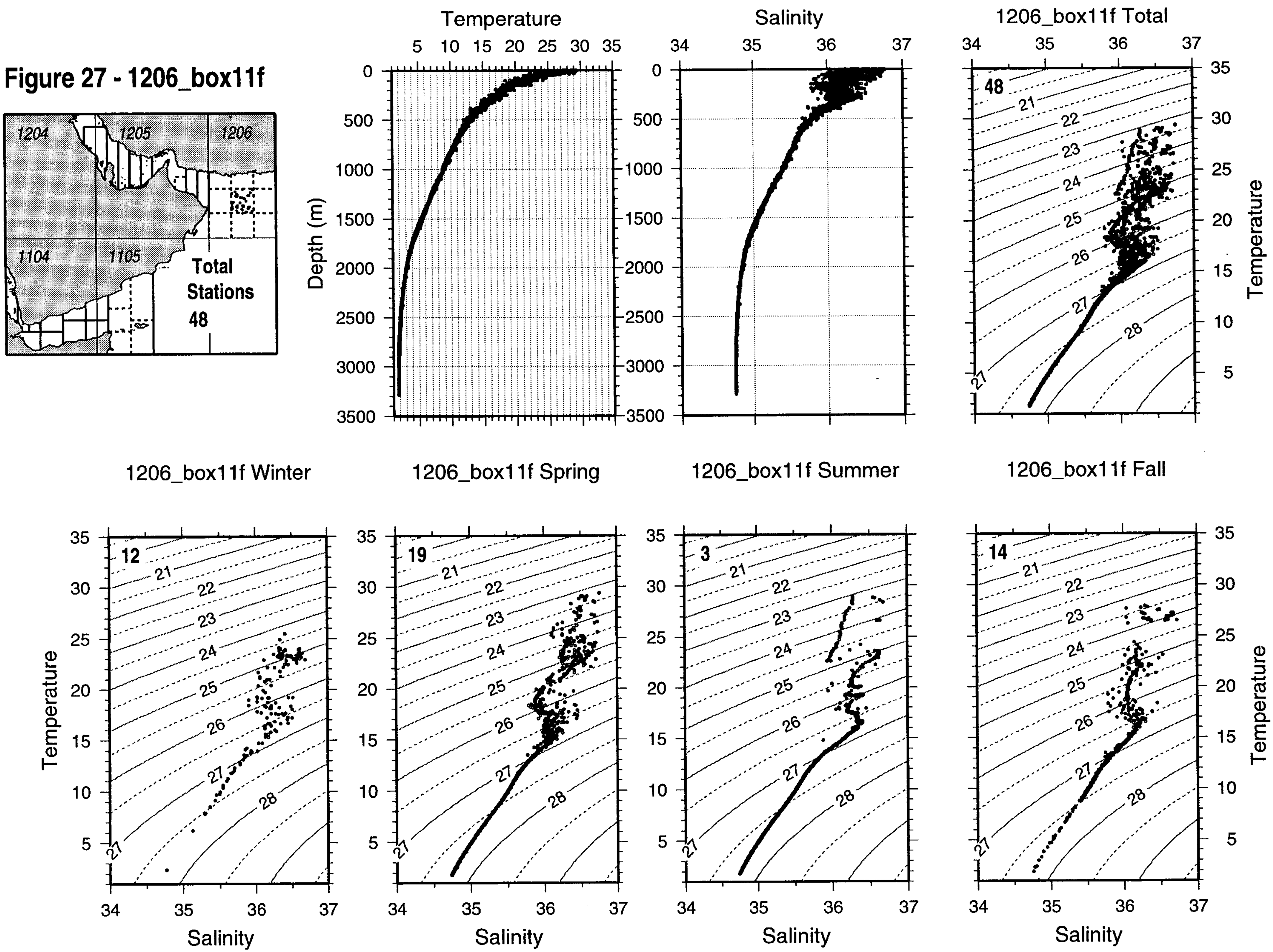


Figure 28 - 1206_box11g

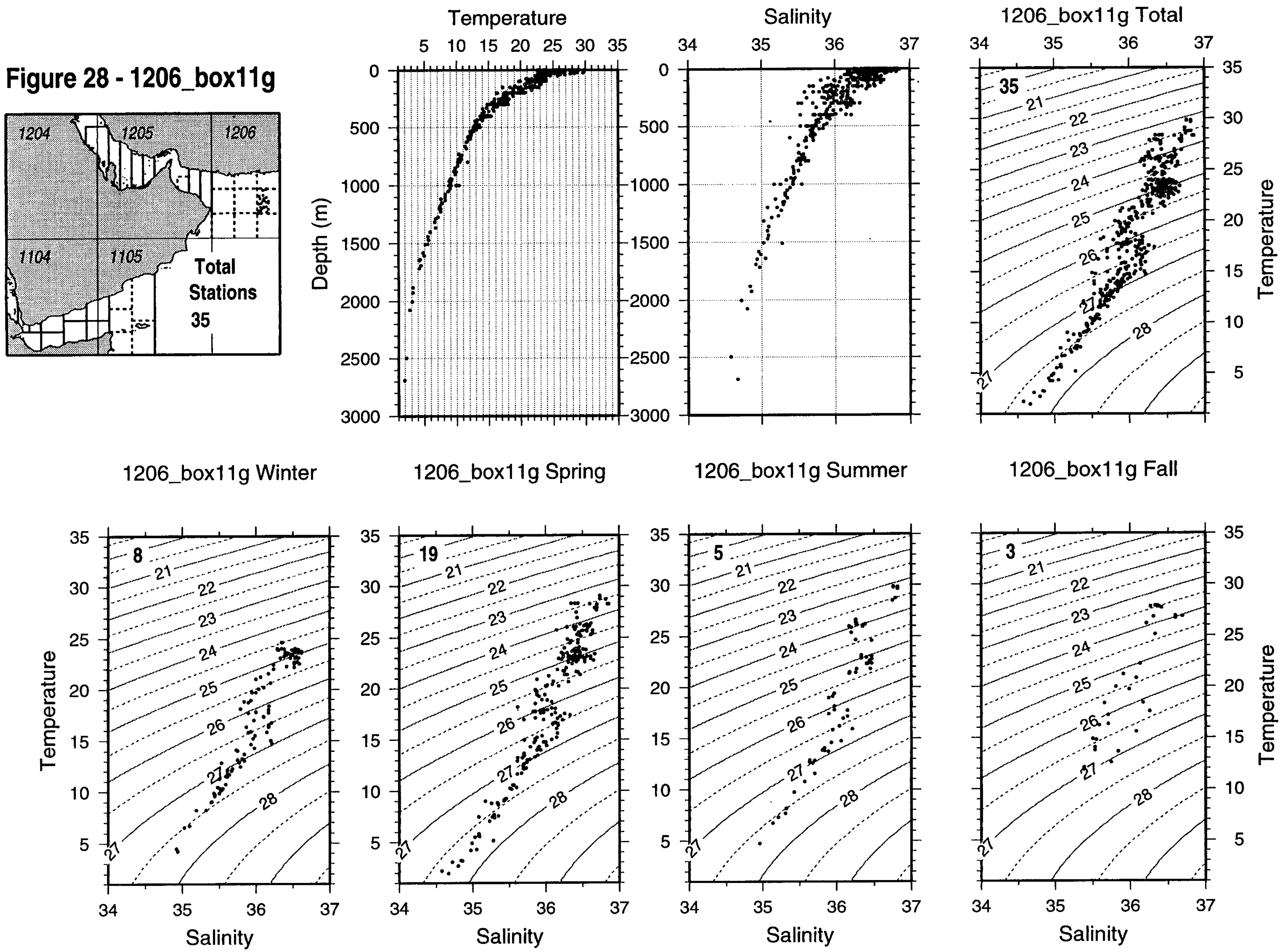


Figure 29 - 1206_box11h

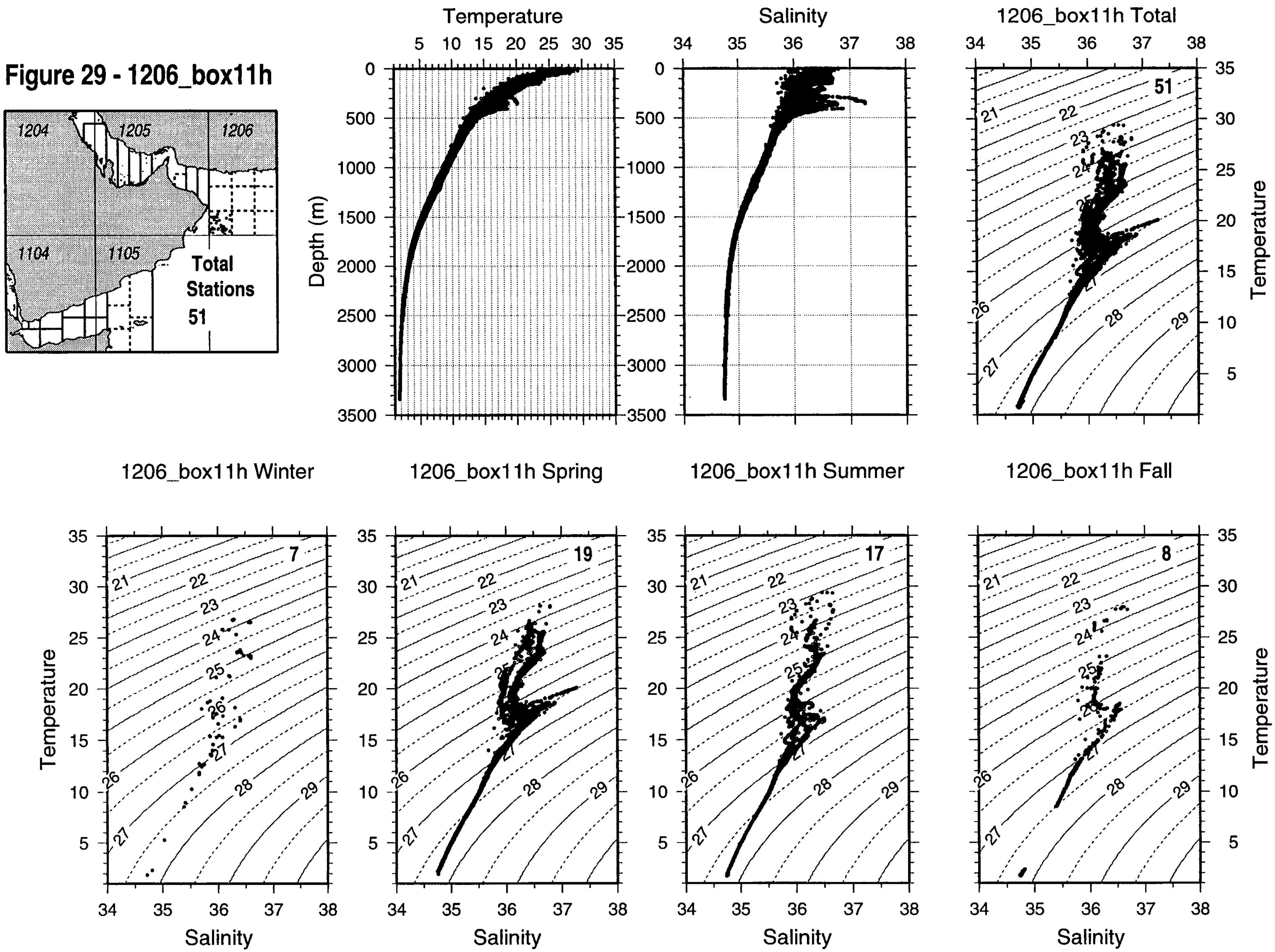


Figure 30 - 1206_box11i

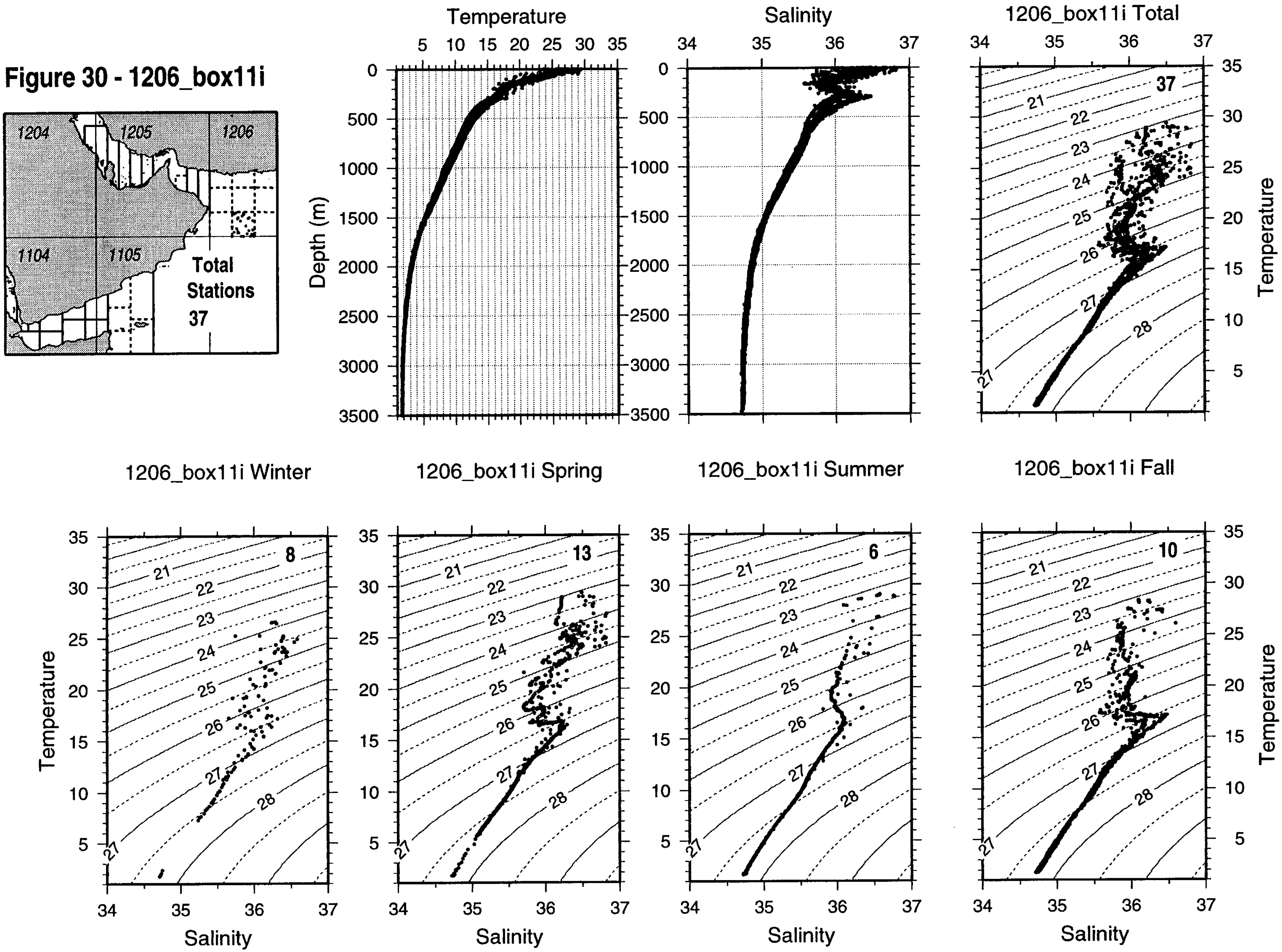
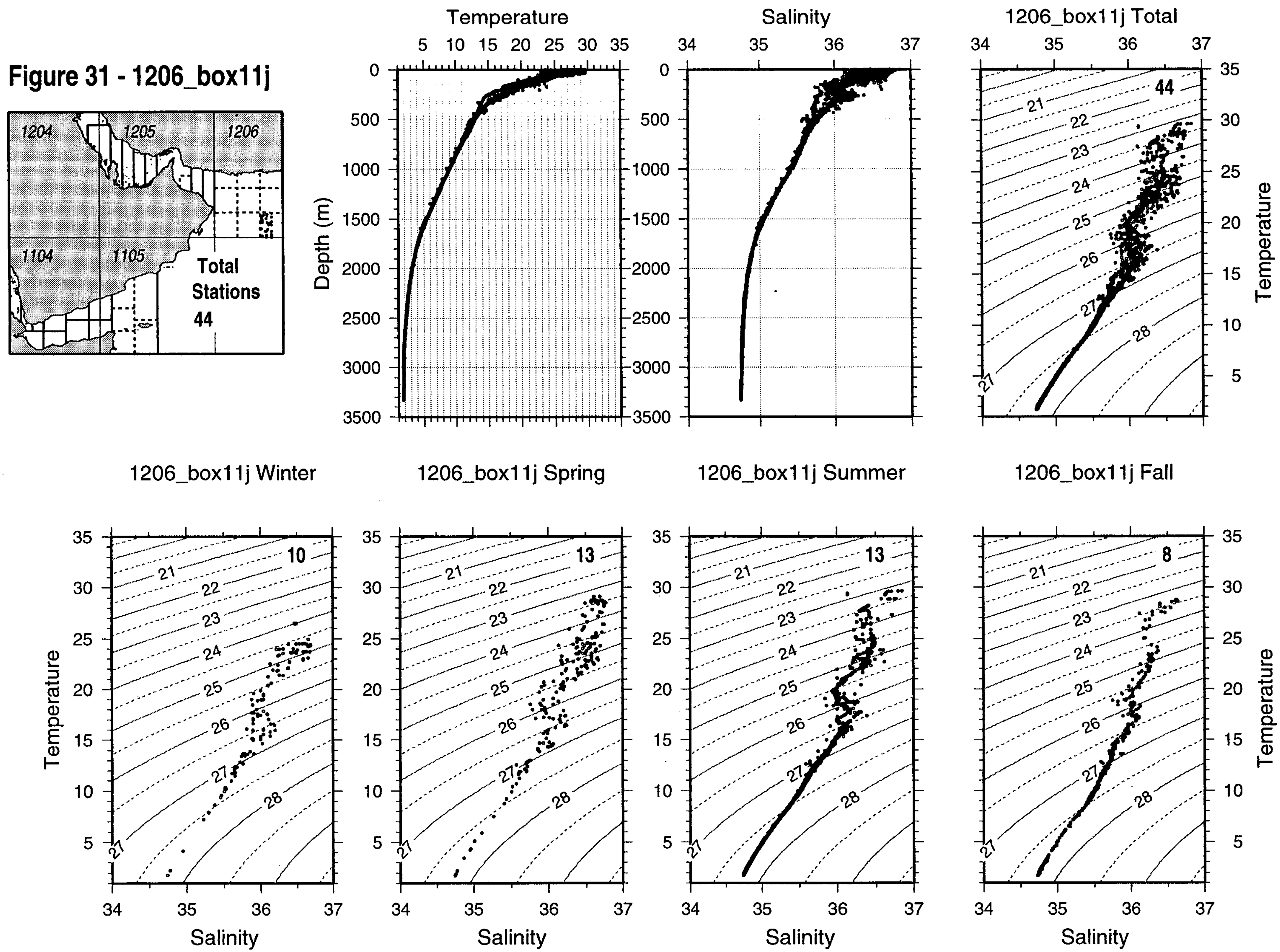


Figure 31 - 1206_box11j



9. Data Presentation for Region 2

Figure 32 - 1104_box1

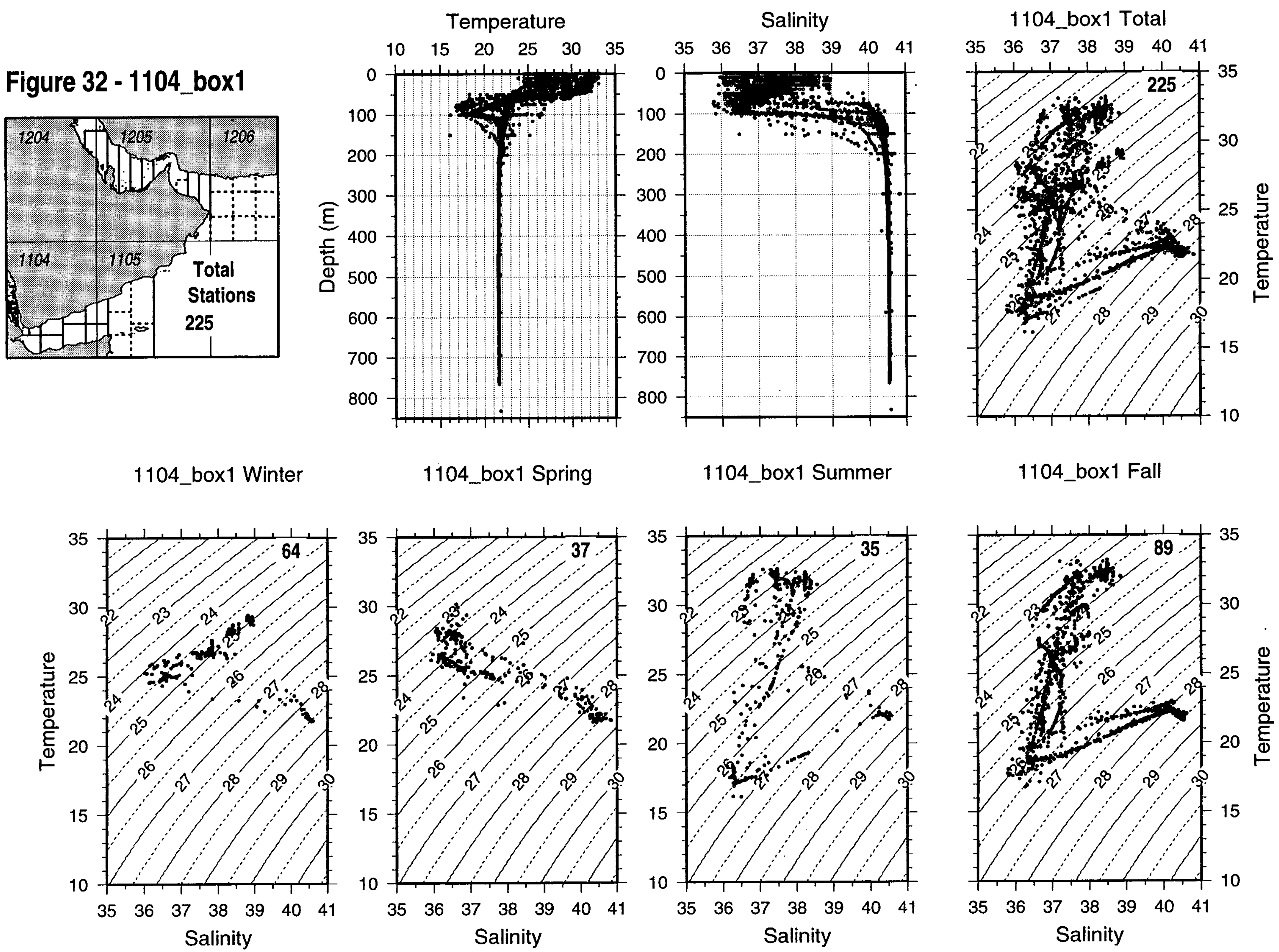


Figure 33 - 1104_box2

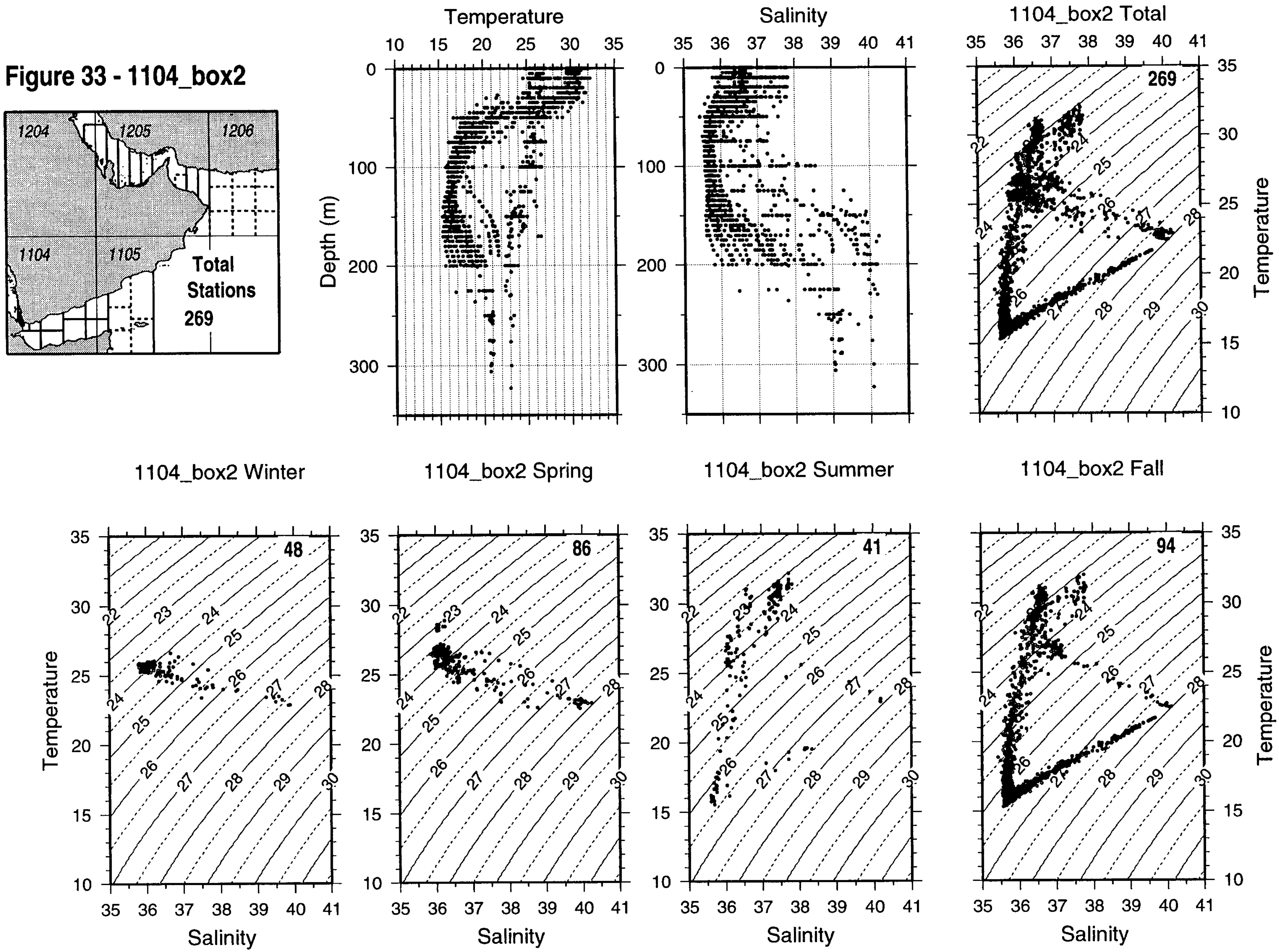


Figure 34 - 1104_box3

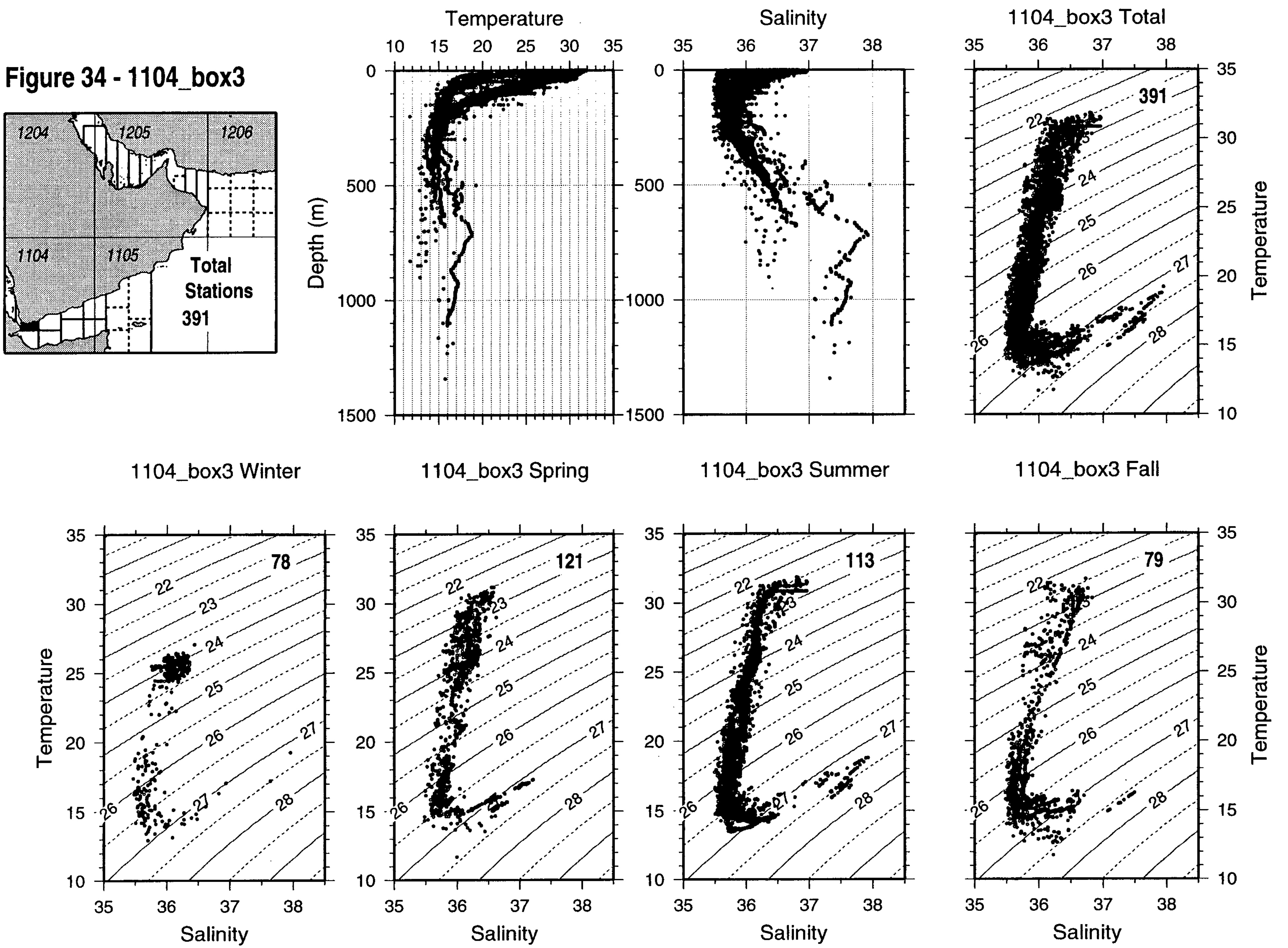


Figure 35 - 1104_box4

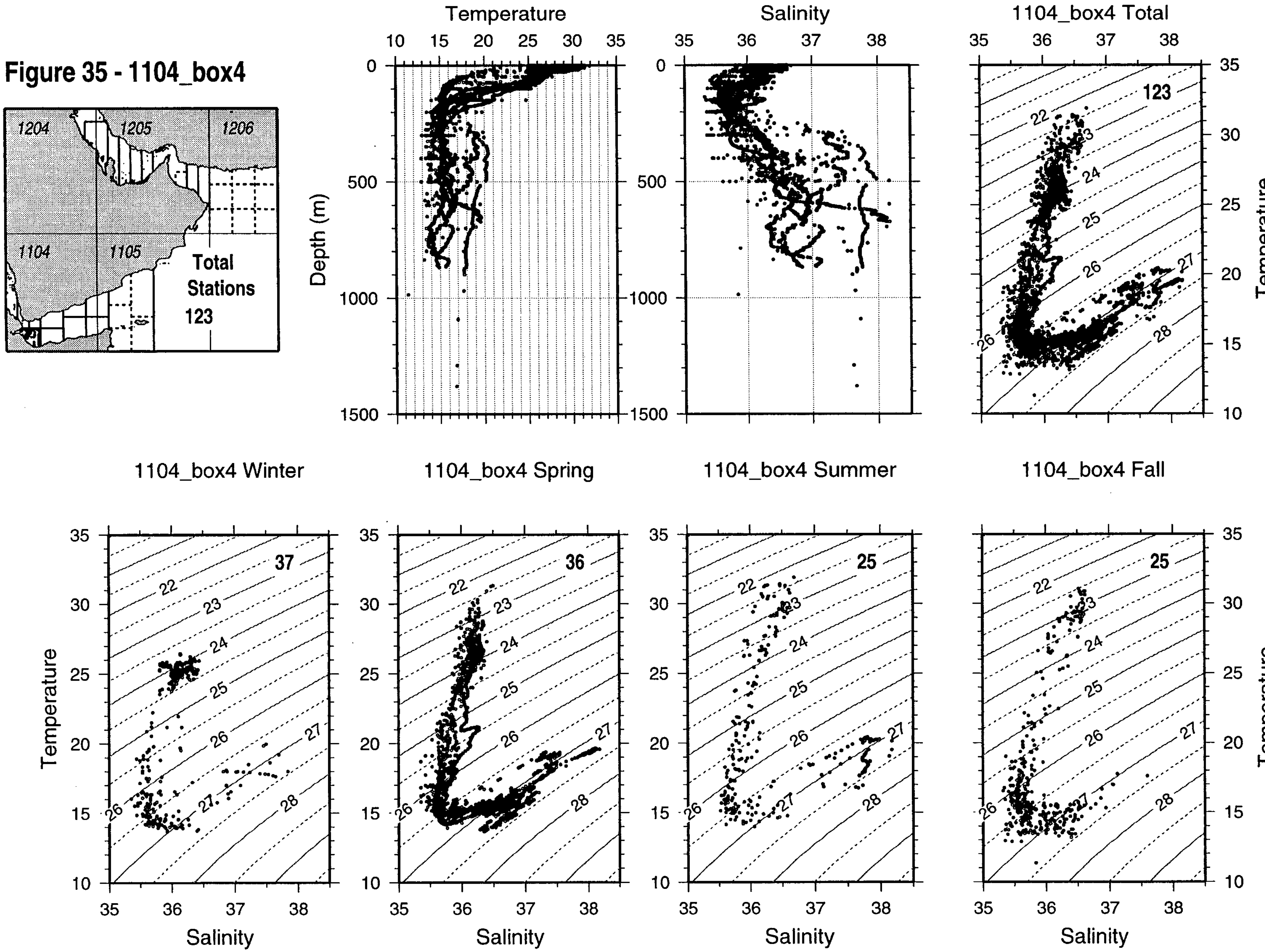
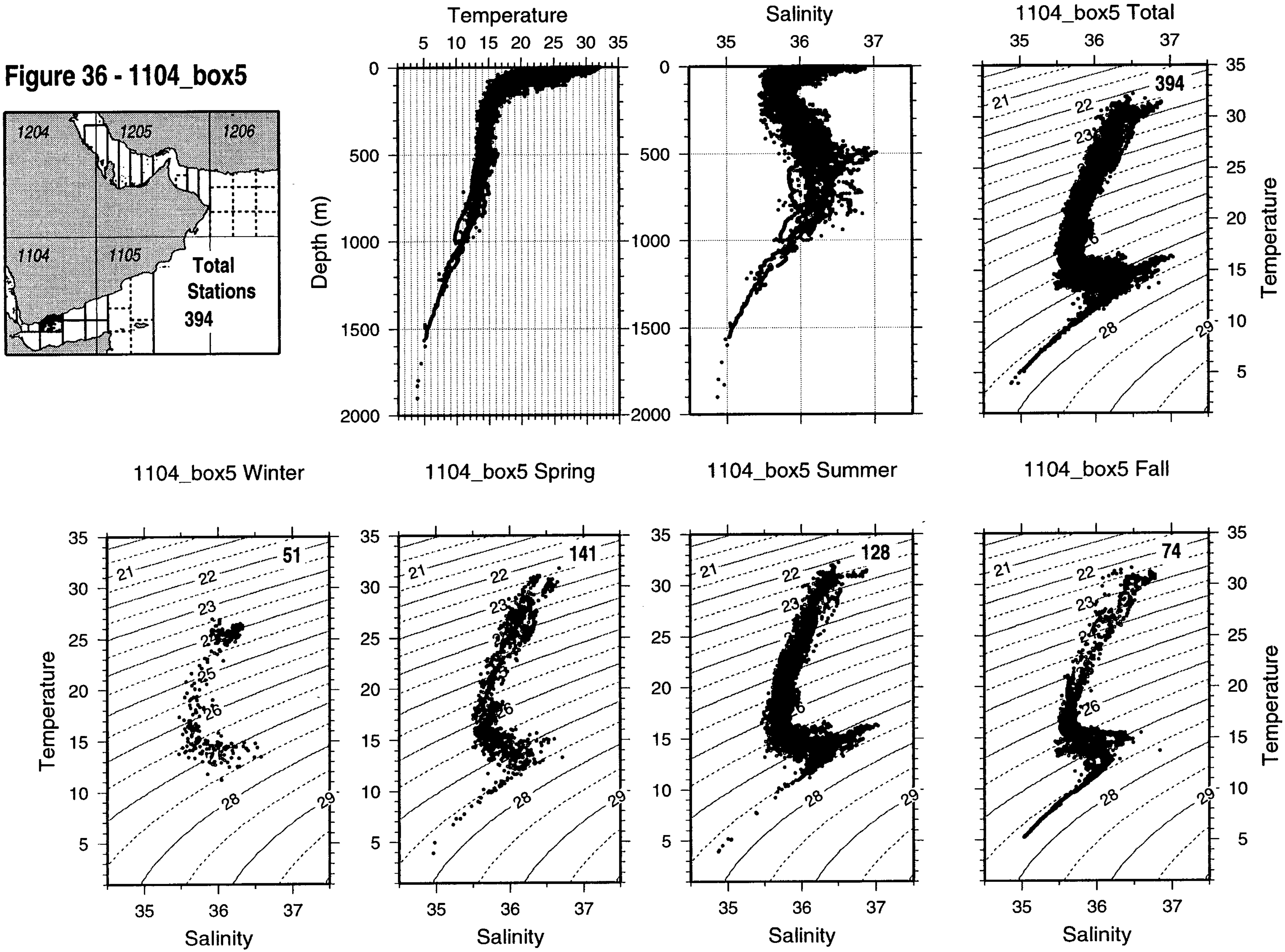


Figure 36 - 1104_box5



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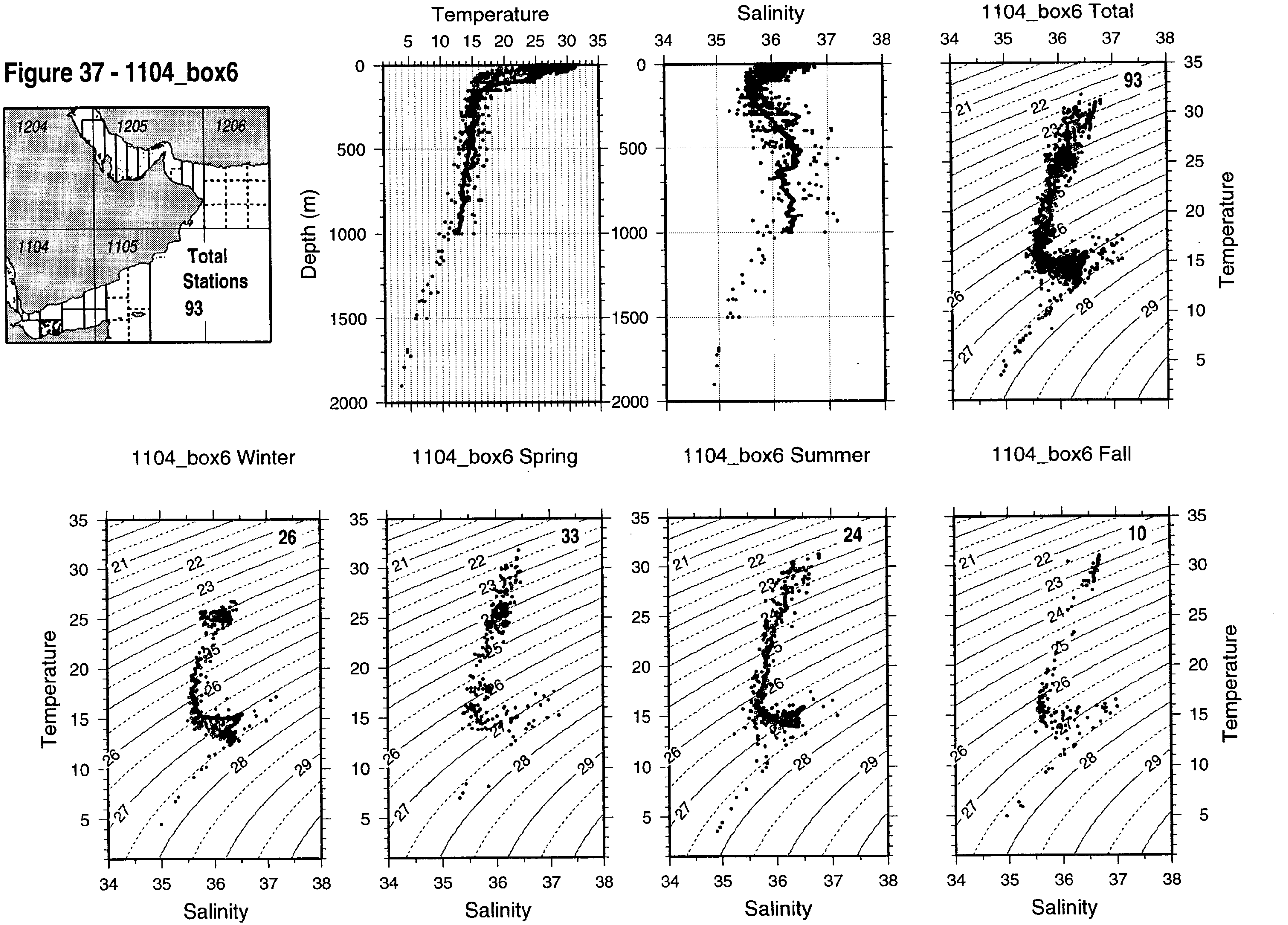

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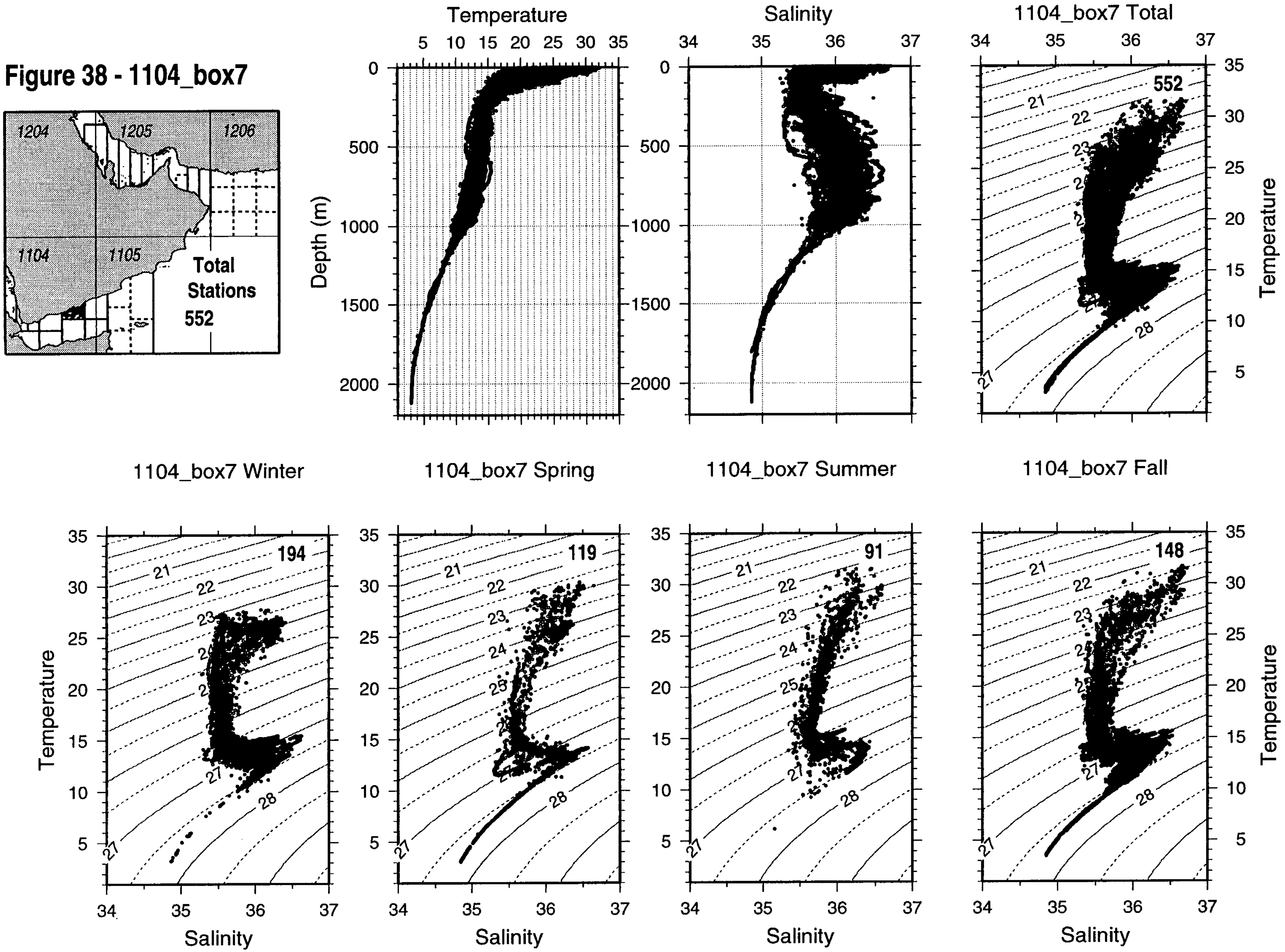

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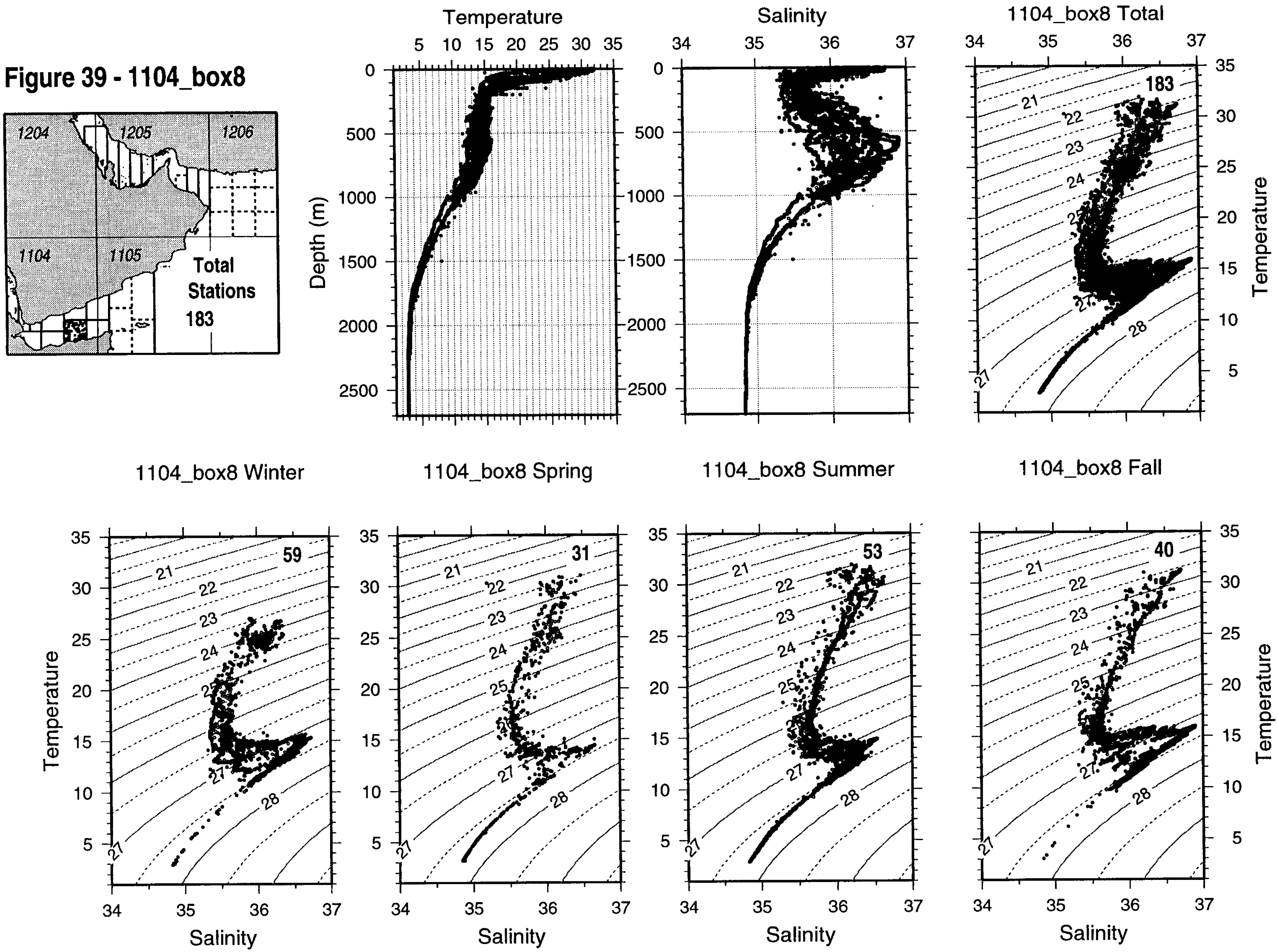

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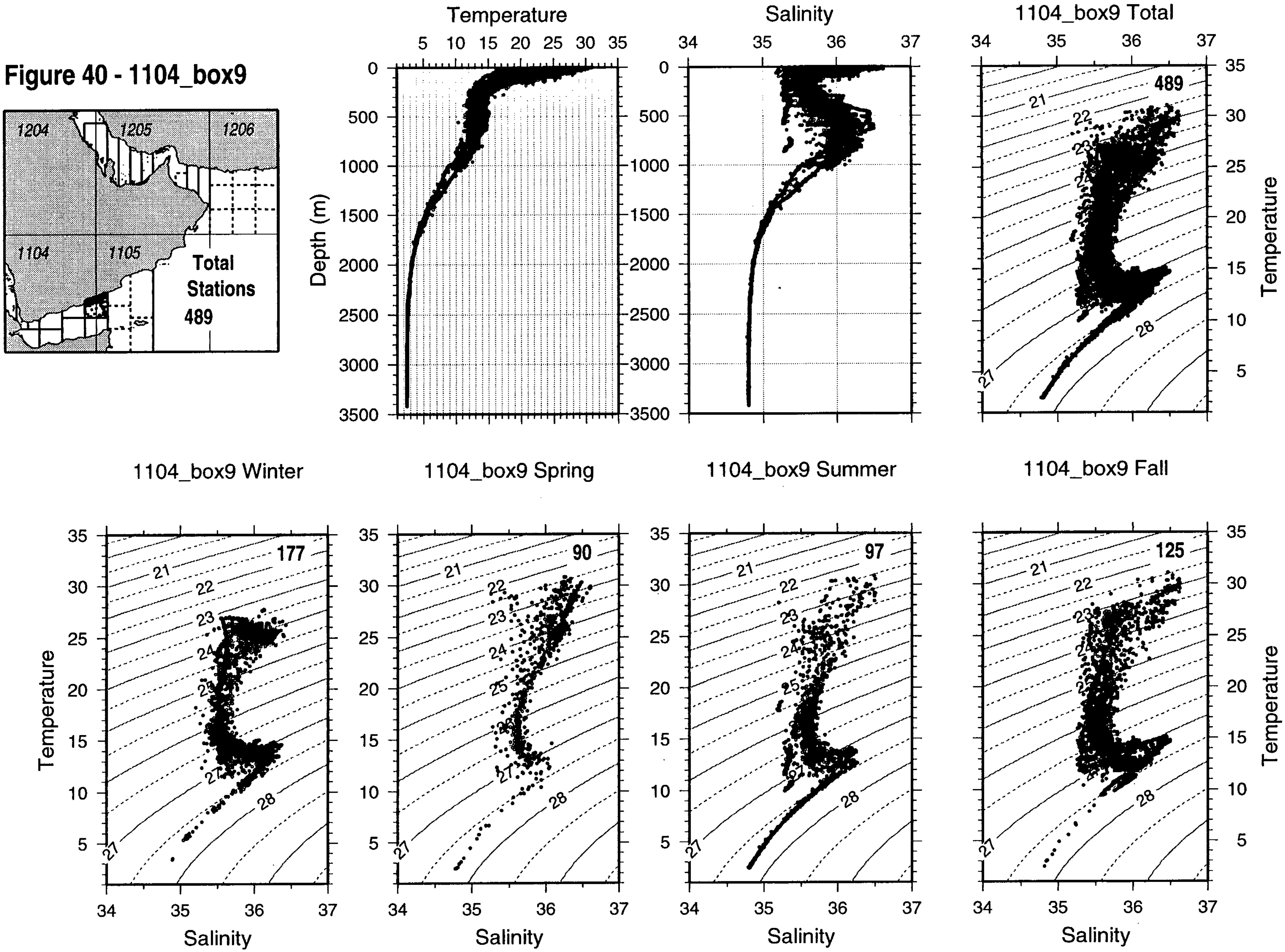

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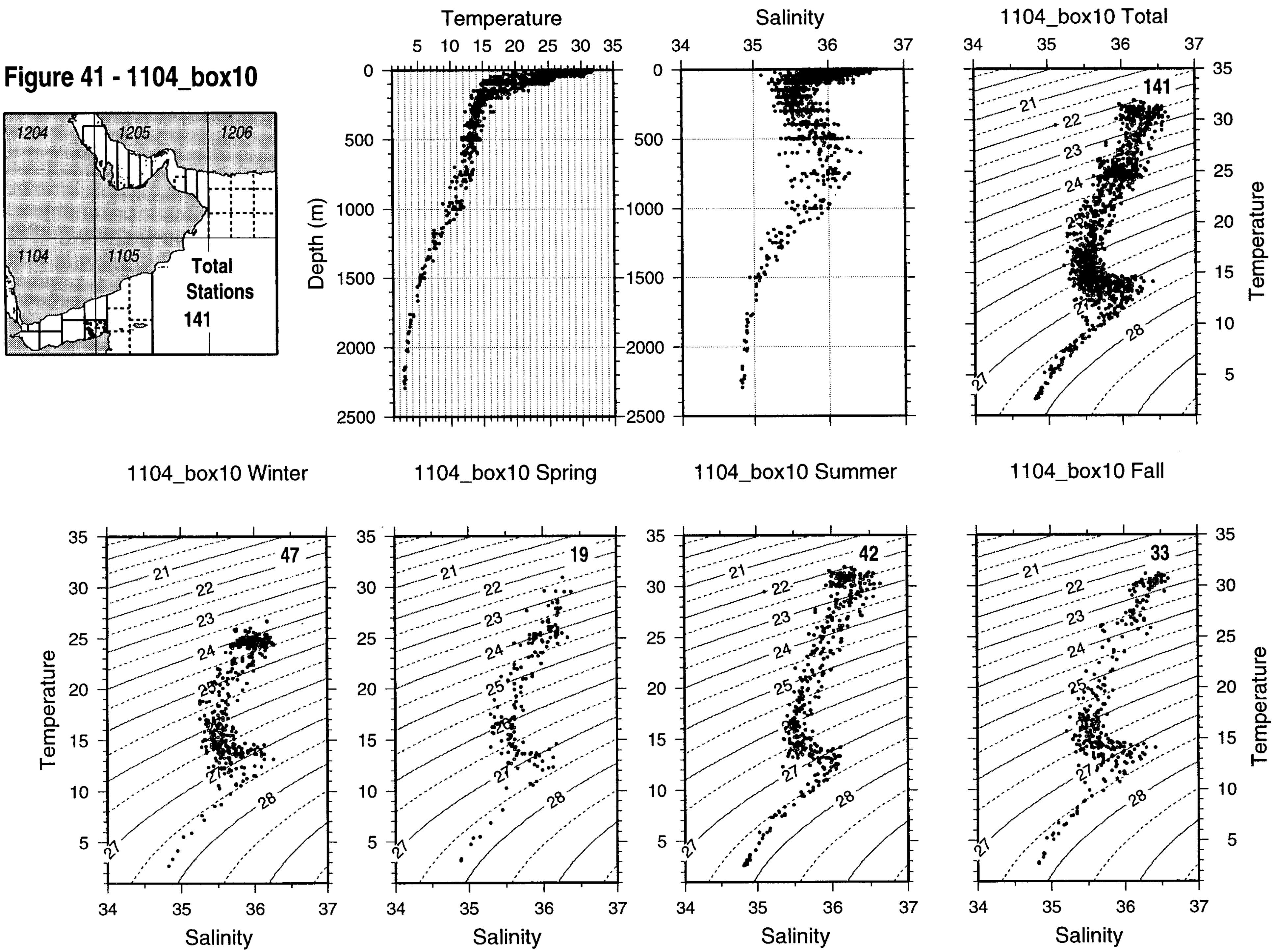


Figure 42 - 1105_52

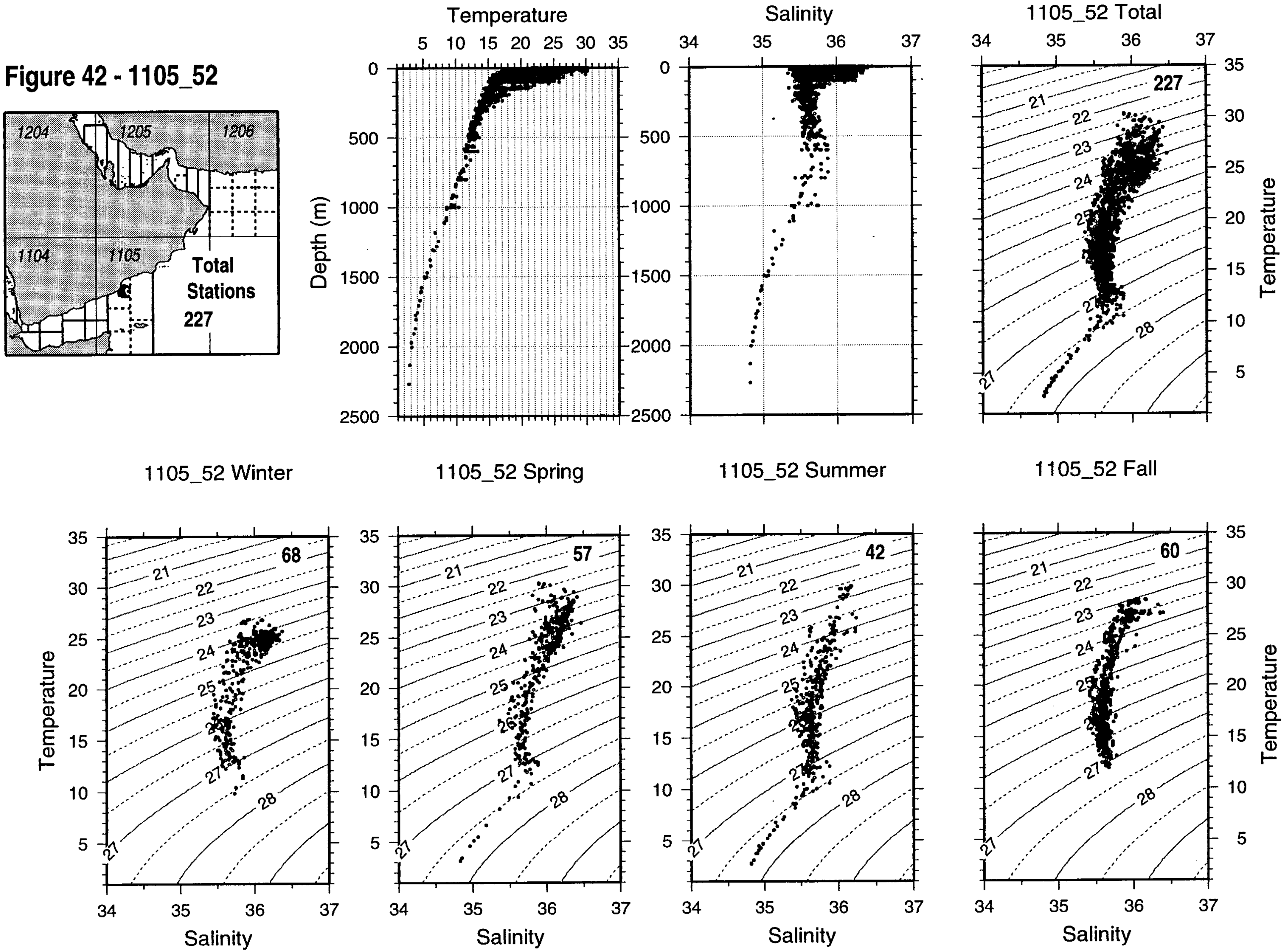
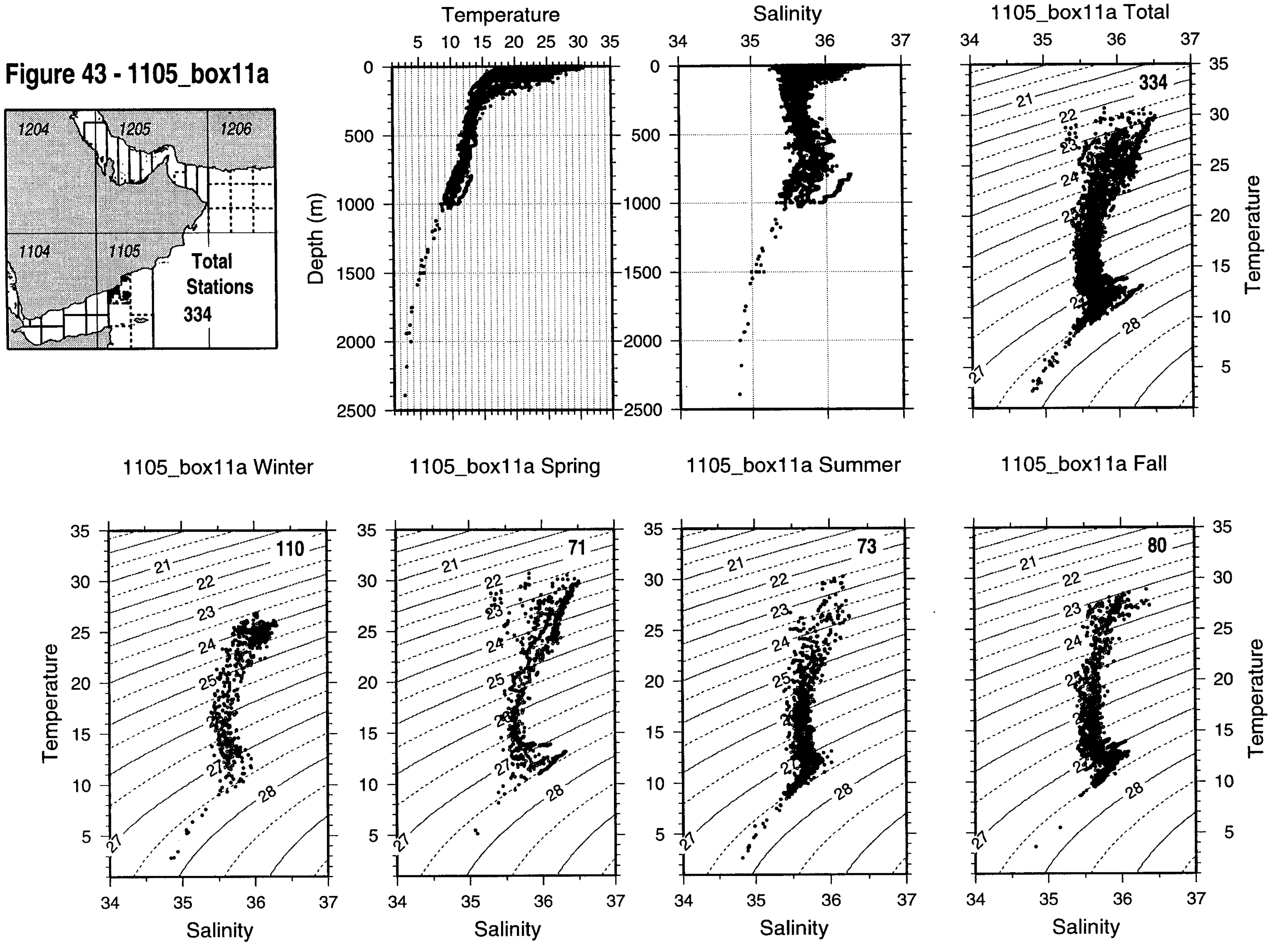


Figure 43 - 1105_box11a



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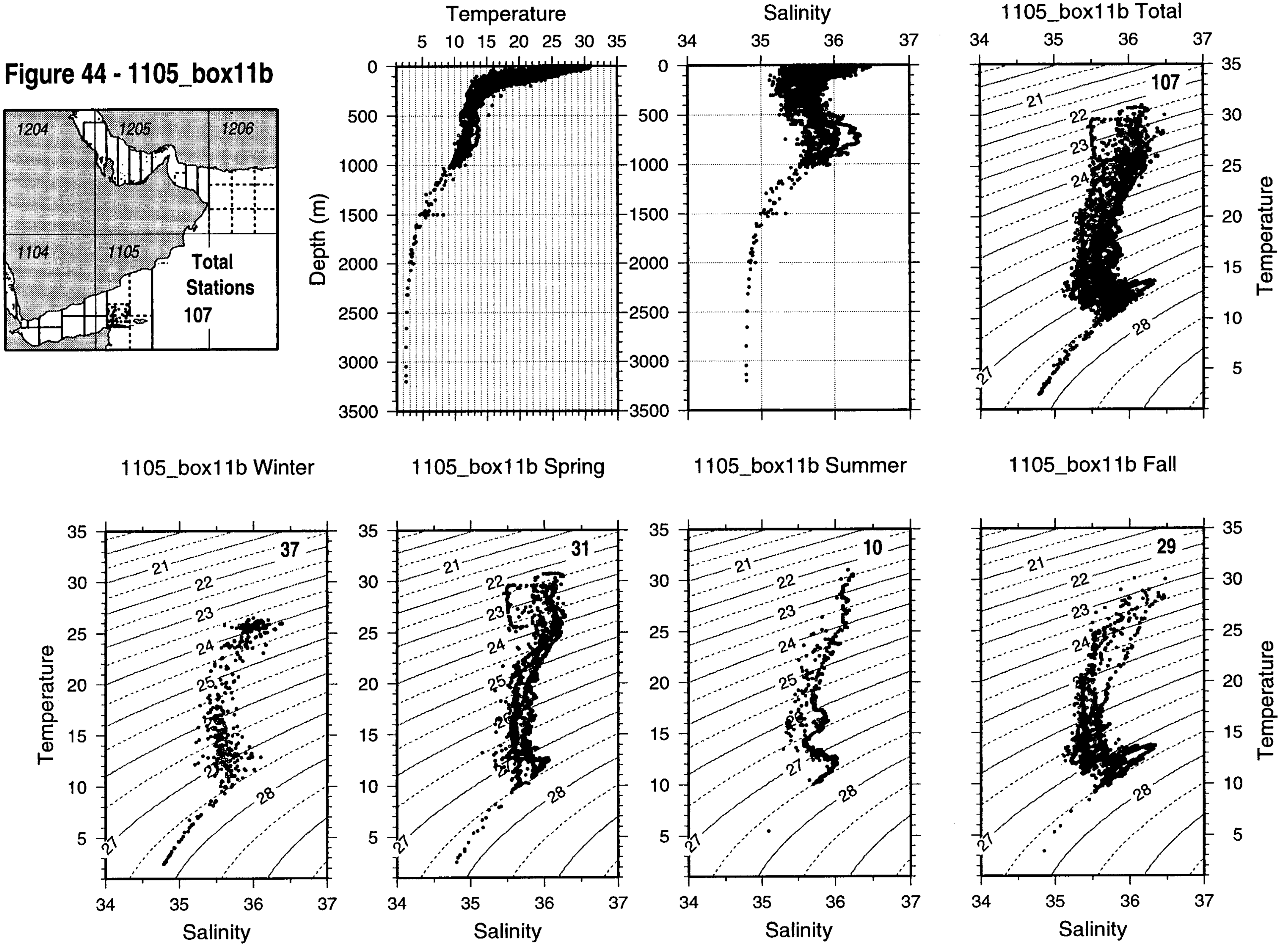

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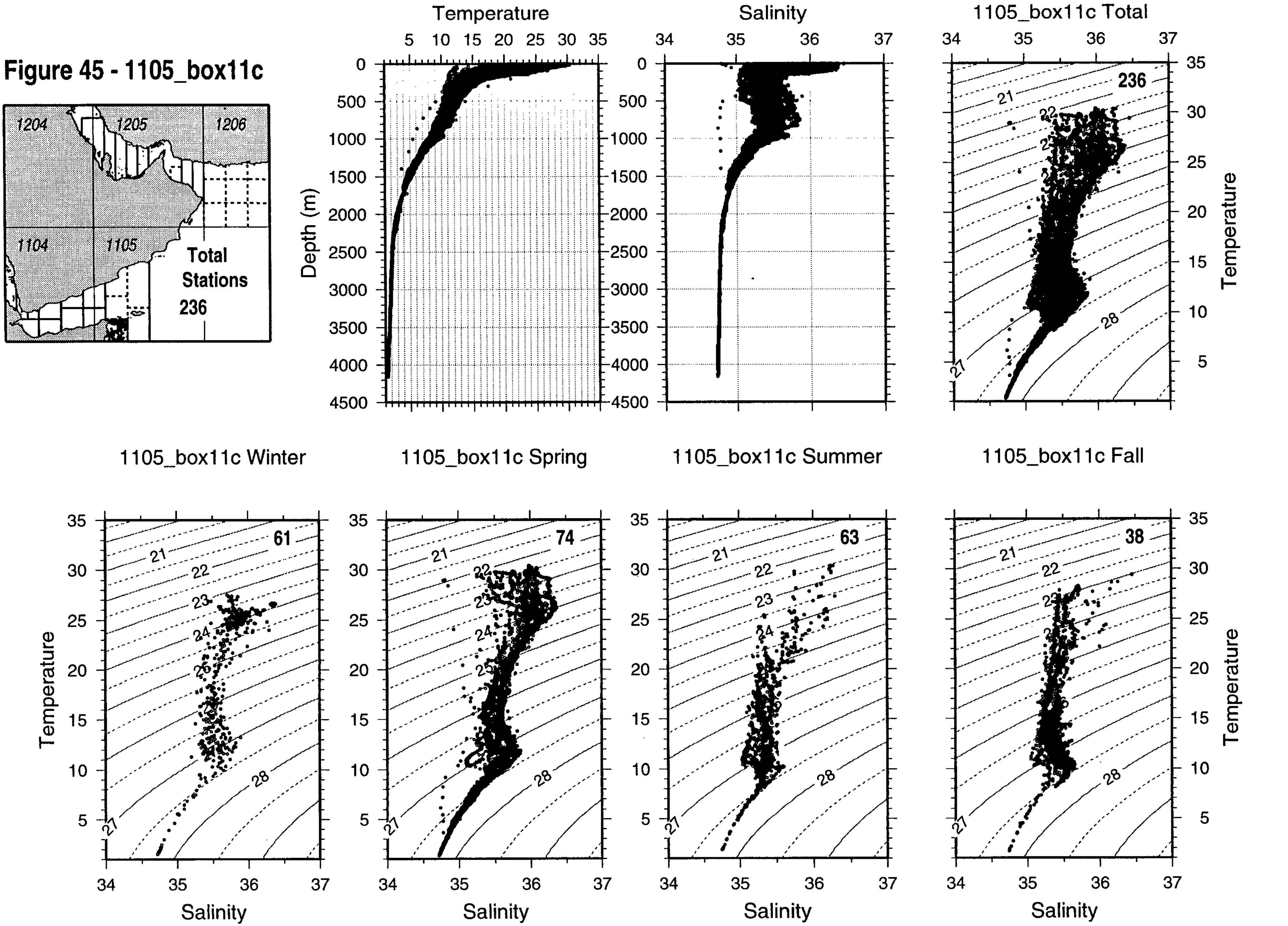

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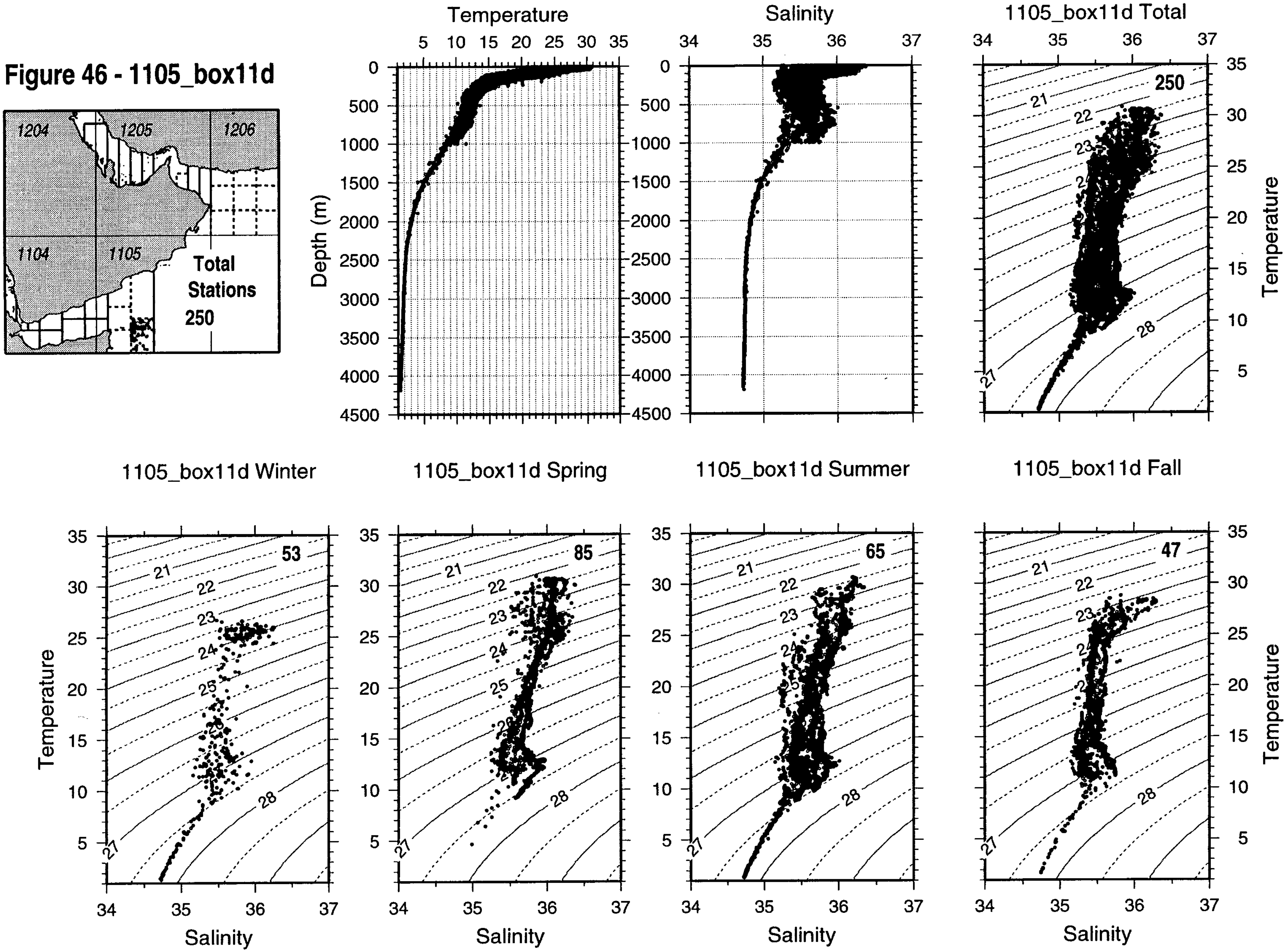

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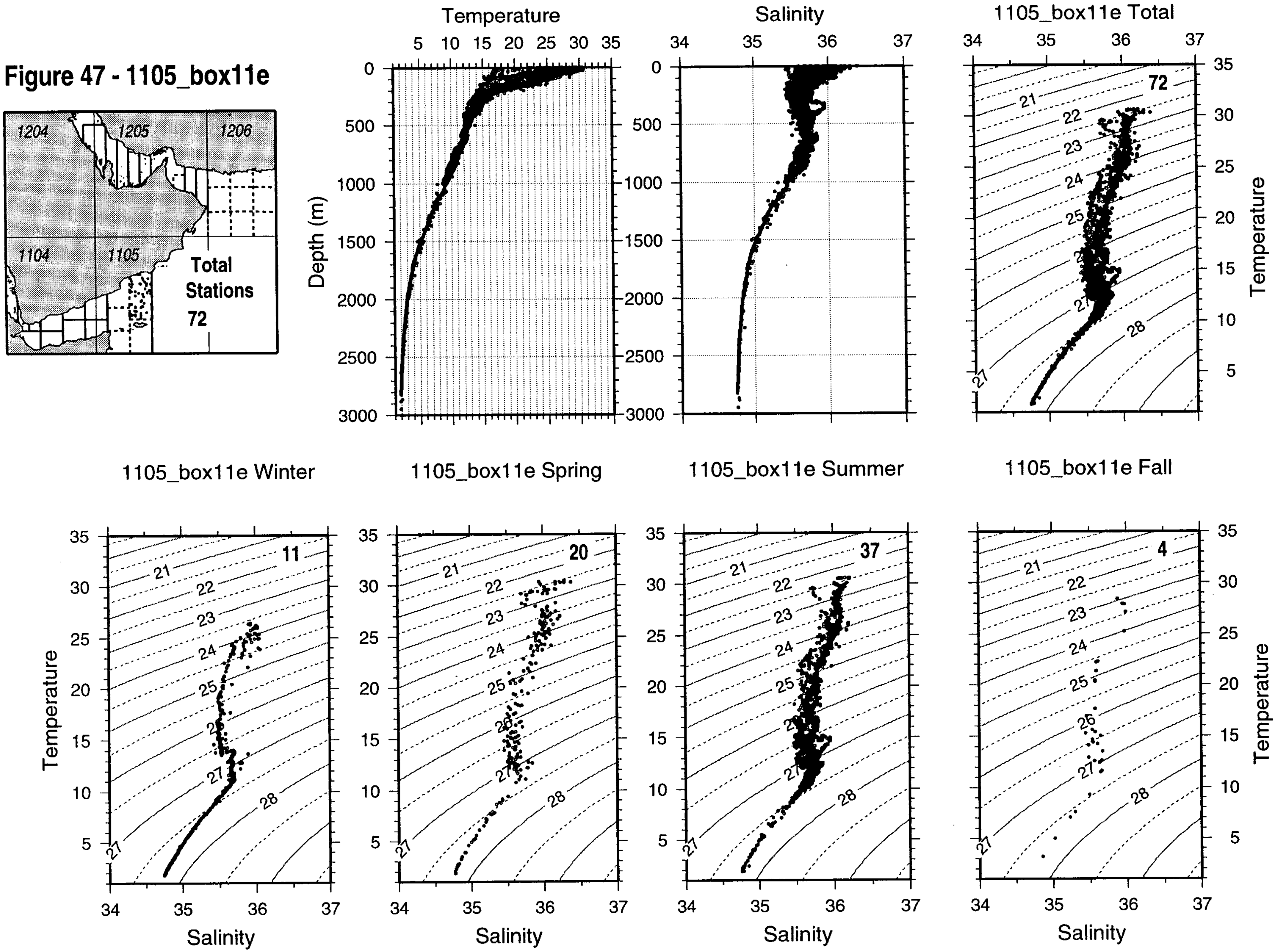

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16. Abstract (Limit: 200 words)

Temperature-salinity-depth profile data were obtained for the Persian Gulf, Southern Red Sea and parts of the Arabian Sea from the Master Oceanographic Observations Data Set (MOODS), located at the U.S. Naval Oceanographic Office (NAVOCEANO), Stennis Space Center, Mississippi. These data were used as part of a physical oceanographic study of the Red Sea and Persian Gulf outflows. This report documents the organization of the data set, method of quality control used to eliminate unrealistic data, and provides a summary in graphic form of the hydrographic observations.

17. Document Analysis a. Descriptors

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Persian Gulf
hydrographic data

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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